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FLUIDIZED BED HEAT TREATING

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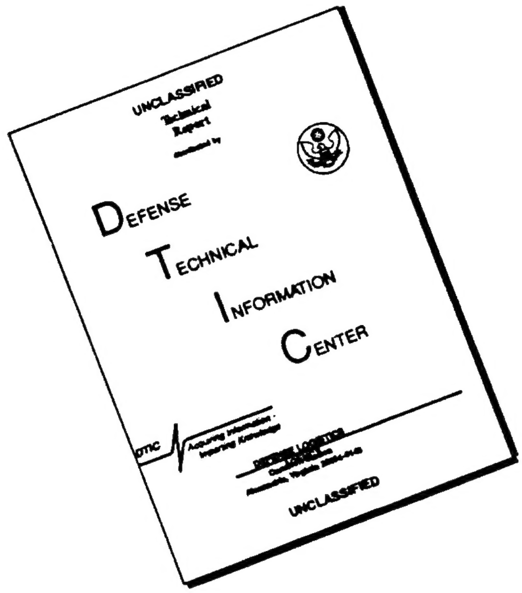

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Steel (carbon, alloy, tool, and stainless), aluminum, titanium, and other metal can be heat treated economically in a fluidized bed furnace. All heat treatments except controlled rate cooling rate annealing are viable. Since gases are used to fluidize a bed of powder, any gaseous atmosphere can be used, and simply by turning a few valves, an atmosphere can be completely changed over in 2 minutes or less. This feature allows multiple heat treating operations to be done in the same furnace without cool down, switching furnaces, and reheating which is standard in commercial shops.

Fluidized bed heat treating is economical, safer, and almost emission free. Data is presented comparing cycle times and cost for the most common heat treatments and results of emissions testing of fluidized beds are presented. Finally, fluidized bed heat treating cycles for steel, aluminum, titanium, magnesium, and copper are given.

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INTRODUCTION

Fluidized bed furnaces are viable, economical choices for many traditional heat treating processes including solution and aging, austenitizing - quenching - tempering, surface hardening, stress relief, and cosmetic oxidizing. All types of steels including carbon, alloy, tool, and stainless, aluminum, titanium, magnesium, copper, and most other metals which are heat treated can be heat treated economically in a fluidized bed.

A schematic of a fluidized bed furnace is shown in figure 1. It operates on the following principles:

- a bed of ceramic (usually but not always aluminum oxide) is contained by a retort.
- at the bottom of the retort is a diffusion plate which allows a gas to be introduced into the bed at a constant pressure and flow all across the area of this diffusion plate.
- the flow rate of the gas (or combination of gases) is sufficient to cause to powder to move so that its properties are more like a liquid than a solid.
- the gas exits the retort through a burnoff stack, where it is combusted to environmentally benign gases.

Since this fluidized bed is acting like a liquid, but consists of a solid, there is a dual phase (solid-liquid) being used to heat up a cold charge of metal. This causes several beneficial conditions. The cold metal is heated approximately twice as fast as it would be by forced gas convection. Since there is a bulk "solid", being agitated by a fluidizing gas, the particle to particle heat transfer creates excellent temperature uniformity within the furnace. The table below illustrates typical uniformities for various furnaces are:

Table 1. Typical uniformities obtained for various types of furnaces

Furnace Type	Uniformity (±°F)
Typical Fluidized Bed	3
Fluidized Bed **Open Retort**	10
Highest Quality Gas Furnace	10
Typical Gas Furnace	25

Fluidized beds are safe and emission levels are orders of magnitude under maximum allowable levels per Clean Air Act of 1990 (0 VOC's and 4 pounds of NOx per year). With a properly designed burnoff stack NO carbon monoxide or ammonia ever gets released into the air.

Finally, procedures have been developed and presented for all types of fluidized bed heat treating. The only kinds of heat treatment not well suited to fluidized beds are annealing, because it takes too long for the fluidized bed to cool down, and bright type heat treating unless an adequate transfer container with an inert atmosphere is employed, because transfer of material from furnace to quench bath is through air.

RATIONALE

This project was undertaken because fluidized bed technology is not considered a traditional method of heat treatment by all. Therefore a handbook of heat treatments by alloy and treatment is desired. Furthermore, cost, cycle time - productivity, and environmental benefits data is presented in order to encourage greater utilization of fluidized bed heat treating.

DISCUSSION

General Heat Treating Considerations

For this study, the processes of solution treating and aging, austenitizing and tempering, stress relief, carburizing, nitriding, carbonitriding, and nitrocarburizing will be considered and discussed. The important variables to consider therefore are times and temperatures (and in some cases quench rates).

Theoretically, heat treatment times should be only the time required to bring the last area (the center of the workpiece) to temperature plus the time required for all diffusion processes to take place. In reality, this calculation is impossible, because there is temperature variation in the furnace, which will greatly affect diffusion rates, and other similar problems. In all cases, treatment times have two components: the first is a heat up time for material to get to temperature. All governing military specifications have some criteria for heat up time. The basis is for the **surface** to get to the minimum specified temperature. The second component is time at temperature. This component allows for all of the interior to get to the minimum specified temperature and also to allow all diffusion processes to occur. Tests conducted showed that the heat transfer coefficient for fluidized beds is approximately double that of forced air convection, and half that of salt (ref 1). In practical terms, heat treating times for fluidized bed processes should fall exactly halfway between those specified for salt baths and air furnaces. Critical temperatures are described in table 2 below. Heat transfer analysis was performed for each alloy class, and in all cases, the center was at temperature well before the minimum required heat treating time, not even considering soak time. Thus, the specifications allow ample time for diffusion processes to occur.

Table 2. Critical heat treating temperatures

Material	Critical Temperature	Reason
Steel (Austenitize)	A_3 or A_{cm}	Fully Transform to Austenite
Al, Ti, Steel (Solution)	Solvus	Fully dissolve low temp. Second Phase into solution.
Steel (Carb. Carbonit)	A_3 or A_{cm}	Diffuse only in fully austenitic state.
Steel (Nit. or Nitrocarb)	Solvus	Diffuse only in fully ferritic state.

Ferrous Heat Treating

Neutral Processing

All of the experience in the fluidized bed heat treating community has in neutral atmosphere heat treating (annealing, stress relieving, normalizing, and austenitizing-quenching-tempering) is based on data supplied in the Heat Treater's Guide (ref 2). Of 19 austenitize-quench-temper points examined, 16 yielded within ± 2 Rc points of the aim hardness, which is the usual range employed in commercial heat treating. The cycles cited specify preheat temperatures, soaking temperatures, and times at soaking temperatures. They do not elaborate on heat-up rates. Appendix A is a compendium of Neutral Processing of ferrous alloys including a table of recommended heat up times for ferrous alloys based on the discussion of heat transfer rates in Section 3.0.

When a fluidized bed is turned off overnight, the next morning, the bed temperature is still 800°F or higher. Since the last step in annealing is a controlled rate cooling, usually requiring 24 hours or more of cooling, and since the fluidized bed is very efficient and environmentally friendly, it should not be tied up in a slow cooling application.

Surface Heat Treatments

There are four (4) surface heat treatments within the scope of this project: carburizing, nitriding, carbonitriding, and nitrocarburizing. For each of these processes, the use of a fluidized bed furnace results in productivity improvements. Appendix B is a compilation of process flow diagrams of traditional vs. fluidized bed heat treating for these case hardening treatments.

The processes of carburizing and carbonitriding are high temperature diffusion processes. The typical commercial heat treater performs these processes in gas atmosphere furnaces. The normal operation entails loading into a cold or warm furnace, sealing, then establishing (or reestablishing) atmosphere, bringing to temperature (or recovering), treating, furnace cooling, unloading, then salt bath (or for large parts neutral gas) hardening. Fluidized bed technology does better. Parts can be charged into a nitrogen atmosphere furnace at temperature. After allowing for recovery (similar times as salt bath), flip the valves to establish carburizing atmosphere, run cycle, switch back to nitrogen, and lower temperature to hardening temperature, austenitize and direct quench. This improvement eliminates an entire furnace cool and reheat operation. There is one additional advantage. In a traditional atmospheric furnace, upon opening the door to quench, carbon monoxide is liberated, and in an enclosed building, this is a significant health hazard. Fumes make breathing more difficult and eyes water. In a fluidized bed, when the carburizing is complete, a nitrogen atmosphere is established, in two minutes. The remainder of the simulated endogas is combusted to benign gas in the burnoff stack. When the atmosphere is completely purged of the carburizing gases, the burnoff stack flame dies out. Upon opening the furnace to quench, only nitrogen is in the furnace, so there are no fumes.

The process of carburization can be performed in two ways. The first way is a straight carburization. A hydrocarbon (usually methanol-natural gas in nitrogen in fluidized beds and endothermic plus enriching gas in traditional furnaces) is combusted. The resultant

CO reacts to form CO_2 and C. This free C is deposited on the steel surface, and begins diffusing. In terms of classical diffusion theory, since a steady carbon concentration is maintained in the furnace, this process is known as infinite source diffusion. The experience of Procedyne and others (ref 3) is that with a 3% natural gas - 60% methanol - 37% nitrogen mixture, a carbon potential of approximately 1.6% is established. This number has been verified in shim stock analysis, and by comparing actual results to predicted results from a mathematical model. Procedyne Corp. is developing a method for continuous on line monitoring of carbon potential. In some applications, the optimum surface carbon concentration is 0.82% carbon, the eutectic composition. More carbon results in heavy carbide formation. To achieve this desired concentration using the same gas mixture, requires a carburization following by a switch over to inert protective gas (nitrogen) without lowering temperature. This allows the excess carbon at the surface to diffuse into the metal, which both lowers the carbon, and increases the case depth (provided the diffusion is not too long). In classical diffusion theory, this is known as a fixed source diffusion. The trade name for this process is the boost-diffusion cycle. By setting appropriate boundary conditions, Fick's laws are solved, and the process is mathematically described for both processes (the boost cycle and the diffusion cycle). Carbonitriding is simultaneous carburizing and nitriding. As such, the responses mirror those of carburization, and the same equations should be used.

When working with carburizing, case depth is described as the distance subsurface, where a microhardness reading corresponding to Rc 50 is obtained. This is the generally accepted method, especially in aerospace and automotive parts (at least in America). At least one other foreign source (ref 4) defines case depth as the distance subsurface where the carbon concentration is 0.07% greater than it is in the core. The mathematical solutions of these two different conditions yield very different solutions. In general, aerospace work on low carbon steel (8620) uses the Rc50 definition. The theoretical basis is treated in Appendix C. This further establishes a need to create a new definition of case depth for tool steels and any other steel to be carburized which has a carbon content greater than .35% carbon, since Rc50 is obtained at a point in the case where the carbon content is .35% carbon. For non-aerospace, non-automotive applications, the commercial practice for case depth determination is to visually measure with a 40x Brinnell scope. Appendix D tabulates all case hardening trials performed and/or published. Figure 2 compares traditional carburizing at 1700°F (the highest practical temperature for conventional furnaces because joints and fittings are not usually high temperature material) and fluidized bed carburizing.

The process of carbonitriding is to be avoided for tool steel processing. Nitrogen is a strong austenite stabilizer. Since this diffusion process occurs in austenite, nitrogen diffusion that occurs during this process will yield unacceptably high levels of austenite; thus this process is to be limited to lower carbon, plain carbon steels. Carburization is also ineffective on tool steels A1, D2, O1 because the as quenched hardness is already in the mid to high Rc50 range from the high carbon. The additional carbon actual causes softening at the surface, probably due to retained austenite: this theory has not yet been verified.

Nitriding and nitrocarburizing are low temperature processes, performed after quenching and tempering, when material is ferritic. Commercial heat treaters perform these operations in large bell furnaces, specially designed for these processes, and only

utilizing ammonia atmospheres. Fluidized beds on the other hand again offer productivity improvements by allowing nitriding to immediately follow tempering in the same fluidized bed furnace immediate after the atmosphere is changed and temperature is lowered. In commercial shops, full cooling is required between the two operations. Figure 3 compares traditional nitriding and fluidized bed nitriding for some plain carbon steels and Figure 4 compares for H type tool steels. The fluidized bed profiles shows much quicker rates for plain carbon steels at all times and quicker rates for tool steels after approximately 7 hours. The only cautionary note is that the fluidized bed cycle is 25°F higher. It should be noted that MIL-S-6090 - Process for Steels Used in Aircraft Carburizing and Nitriding limits temperature to 975°F. The original paper defining the Floe Process (ref 5) allows for second stage nitriding to be boosted by as much as 50°F. Furthermore, Notice 2 (Notice of Inactivation for New Design) states that future acquisition for this material should refer to AMS 2759, Heat Treatment of Steel Parts, General Requirements ,, and makes reference to the specific process of Nitriding. The authors heat treating experience suggests that the AMS specification was written for the Floe Process, which allows the temperature boost.

Additional literature searching (ref 6) indicates that most ferrous material can be nitrocarburized. It is especially effective on low carbon material (such as 1020).

The process of nitriding has not been as soundly modeled as carburizing. All known experience and results of fluidized bed carbonitriding, nitriding, and nitrocarburizing (limited) are shown in Appendix D.

Aluminum Heat Treating Using Fluidized Bed Furnaces

The material heat treated in the largest quantity after ferrous metals is aluminum. It is used in airframe components and various automotive uses. There are many alloys, and heat treating for military applications is governed by the specification - MIL-H-6088.

Heat treating in fluidized furnaces offer the same advantages as those for steels:

1. They are an environmentally friendly alternative to salt, exhibiting no environmental hazards. When using a salt bath specifically for aluminum, rectification for pH renders the salt a hazardous chemical. Disposal costs are $2000 per 55 gallon drum. An alternative is to pump out 25% of the volume, and adding virgin salts. This option costs approximately two days of production.
2. They are much more productive than conventional air furnaces, and exhibit uniformity which matches or exceeds that of the BEST air furnaces available. This is particularly advantageous in the solution treatment, where one needs to be as close as possible to the incipient melting point, without any spot ever seeing this eutectic melting point.

This chapter will cover those variables which are important for heat treating of aluminum alloys, and discuss the control of these variables as they apply to fluidized bed heat treating. The three major processes in the heat treatment of aluminum alloys include solution treating, quenching, and aging.

Solution Heat Treating

Solution heat treating requires heating duplex or ternary aluminum alloys from a two phase region, into a one phase region, as close to the solidus curve as possible. The highest temperature achievable without eutectic melting is desired because any and all precipitates need be dissolved into solution (ref 7). The higher the temperature, the higher the diffusion rate (ref 7). Furnace uniformity requirements are according to AMS 2750, which requires a uniformity of ±10°F. This requirement is considered severe by many commercial heat treaters. Fluidized beds are easily capable of this uniformity (ref 8). This means that danger of eutectic melting and intergranular corrosion (see MIL-H-6088 4.5.3) is further reduced. Furthermore, because of the high heat transfer coefficient of the alumina component, parts can be charged directly into a hot furnace AT temperature, with a minimal heat up time, since only temperature losses should be no more than 100 degrees, as opposed to 200 - 300 for a large volume air furnace. Some OEM specifications require a solution heat treating time AT TEMPERATURE of 12 hours or more for castings, using this treatment as a combination of homogenization and solution heat treating. Since fluidized beds have rates similar to those of salt baths, it is possible to reduce every heat up cycle by 50% because of the high heat transfer coefficient and the ability to rapidly charge the furnace. Table 3 shows productivity gains in real terms for commercial heat treating shops using to fluidized bed furnaces.

TABLE 3

		Anticipated Heat Up		Loads per Week		Productivity
Material	Required Soak Time	Air	Fluidized Bed	Air	Fluidized Bed	Gain
Castings	12 hours	2 hr.	1 hr.	8	9	12.5 %
1" parts	2 hrs Air 1.5 F.B.	1	.5	40	60	33 %

Similar savings can be estimated for any sized part. These numbers can be justified, especially since footnote 3 & 4 of Table IV of MIL-H-6088 specifically state "Soaking time in salt bath furnaces begins at the time of immersion except when, owing to a heavy charge, the temperature of the bath drops below the specified minimum: in such cases, soaking time begins when the bath reaches the specified minimum." and also " Soaking time in air furnaces begins when all furnace control instruments indicate recovery to the minimum of the process range."

Any solution treatment performed in a fluidized bed should be done in accordance with Table II of MIL-H-6088. Heat up rates should follow the guidelines in Appendix E, based on the difference between fluidized beds, air heating, and salt bath heating.

Quenching

This is the most important part of aluminum heat treating. The important variable is cooling rate. Factors affecting cooling rate include quenchant used, quenchant temperature, agitation rate, and in the case of polymer quenchants, concentration of the solution. MIL-H-6088 does not treat the subject of polymer quenching. For several alloys it suggests that polymer quenching is not permissible, specifying water at certain temperatures, air cooling, and hot oil, but allows polymers by stating "unless otherwise specified in a drawing or procurement document." Commercial heat treaters depend on governing OEM specifications to determine when to use polymer quenchants. Boeing Aircraft Company's aluminum heat treating specification defines not only for what alloys and forms (casting, forging, wrought product, etc.) polymer quench can be used: but it

also lists required temperature of polymer. There are several factors to consider when selecting a quench system: the strength level required in the part, the degree of corrosion resistance, the amount of distortion which can be tolerated. Often times these are conflicting goals, and the choice of quenchant is made by trade-off.

Critical cooling rates to develop maximum strength levels is the basis for quench design (ref 9). Various critical cooling curves (ref 10) have been plotted, and more recently methods and equations describing the derivation of these curves have been derived (ref 11). Very recently, a new method for determining whether a particular quenchant will produce desired properties was developed (ref 12). This method requires some test runs to measure cooling rates in various section thicknesses, using the intend alloy and quenchant under various operating conditions. By comparing the actual cooling curves to the critical cooling curve, a quench factor Q is developed. By developing different Q values for different quenchants at different temperatures, concentrations, and agitation rates, it now becomes possible to determine under what conditions polymer quenching can be used, and even when a polymer will give a more vigorous quench than water.

Foremost in the design of a quenching system is how much weight will go into a quench, what is the material, what temperature will it be quenched from, and how much of a temperature rise will the quenchant be allowed to see. Boeing Aircraft Company specifications (BAC-5602) explicitly specifies that the maximum allowable rise in quenchant temperature is 10°F. As this is the only such specification so far encountered it will be used as the standard. Some other assumptions which have been made include:

- The aluminum will be quenched from 1050° to 100°.
- The quenchant will absorb all the heat lost, and only gain 10°.
- For a safety factor, the amount of quenchant will be the minimum volume required by calculation plus 20%.

Necessary quenchant amounts for different charge weights of aluminum are shown in table 4. In a factory, where there are many furnaces, and frequent quenchings through each quench tank, an agitator and heat exchanger should be built into the quench tank.

Table 4. Calculation of quench tank requirements

Charge Wt.(#)	Al. ΔT	Water ΔT	Heat Loss Al	Water Needed (# - gal)	
20	950	10	4617	554	66.5
50	950	10	11543	1385	166
100	950	10	23085	2770	332
500	950	10	115425	13851	1661
1000	950	10	230850	27702	3322
2000	950	10	461700	55404	6644

A fluidized bed furnace with adjacent water or polymer quench tank is very well suited to aluminum heat treating. Though, automated transfer especially of large pieces would be difficult and expensive, manual transfer is easily achieved in the 5 seconds allowed by the most stringent transfer. Pieces as large as 6 foot long aluminum sheets are direct quenched within the required 5 seconds. The other factor which makes fluidized beds a

good choice for aluminum heat treatment is that uniformity WITH THE RETORT OPEN, has been measured by an independent vendor as ±10°F. This means that the cover can be opened for the transfer, and a multibasket load can be quenched one basket at a time. The balance of the load still in the bed does not notice any effective temperature change. Furthermore, because of this uniformity, an additional basket(s) can be loaded part way through the cycle of a previously inserted load with no detrimental effect, further enhancing productivity.

Aging

The last heat treatment for aluminum is aging. Any aging treatment performed in fluidized bed furnaces should be performed in accordance with Table VII of MIL-H-6088. Some of the significant aging cycles are as follows:

Table 5: Various temper treatments

T4	aging is a natural room temperature age, in the vicinity of 96 hours, following solution treating and quenching.
T3	natural aging following deformation without any solution treating.
T6	aging cycles designed to produce the highest strength, without sacrificing other properties.
T7	tempers which are overaged, or aged past the temperature - time combination which will produce maximum hardness. The T73 has been developed to minimize stress corrosion cracking of large, machined parts. T76 is to develop a higher resistance to exfoliation corrosion than the T6. Both T73 and T76 consist of aging at two different temperatures. Higher strengths are achieved by aging first at a lower temperature using a slow controlled heat up, while the higher temperature cycle develops the superior corrosion resistance.
T8	tempers have strains introduced between solution treating & quenching and aging, in order to nucleate a finer denser precipitate dispersion.

Appendix F is a compilation of solution and aging heat treatments specified by MIL-H-6088.

Heat Treatment of Titanium in Fluidized Beds

General

Heat treating of titanium alloys for military applications is governed by MIL-H-81200. There are four types of titanium: commercially pure, alpha alloys, beta alloys, and alpha-beta alloys. Applicable titanium heat treatments include: solution and aging, annealing, and stress relief. Treatment times in the tables do not include heat up time. As in the case of steel, soak time shall be considered to begin as soon as the lowest reading control thermocouple is at the lower limit of the specified treatment temperature range. Longer soak times may be necessary for forgings. Shorter soak times are satisfactory when soak time is accurately determined from thermocouples attached to the load. These requirements are from Tables 1 & 2 in MIL-H-81200.

Solution and Aging

Solution and aging is performed on alpha beta alloys and beta alloys. For maximum strength in alpha beta alloys, the solution temperature should be as close as practical to the beta transus temperature. Commercially, this means 50 to 150°F below the beta transus. This is based on the ±25°F uniformity typical of commercial heat treating furnaces. Since the fluidized bed will have a much better uniformity, material could be run much closer to the beta transus, and as diffusion rates increase, treatment times could decrease accordingly (actual process times would still be set based on experimental data).

Quenching is the critical operation in obtaining maximum strength in alpha beta alloys. In commercial shops, cold water is used: brine or caustic soda is even better. In alloys with only small amounts of beta stabilizers such as Ti-6Al-4V, the beta phase can start to precipitate out within 10 seconds, so a rapid transfer time to quenching is required. This rapid precipitation combined with a slow heat transfer rate means that the center sections of heavier pieces cannot develop maximum tensile properties. Duplex alloys with more beta stabilizers such as Ti-5Al-2Sn-2Zr-4Mo-4Cr, can be fan cooled and develop maximum tensile properties. Beta alloys can be air cooled and still develop required properties.

According to specification, transfer between furnace and quench must be completed within 5 seconds. As is the case with aluminum, this is easily performed manually, provided that the piece weight is light enough for easy lifting. Also, as is the case with aluminum, the entire load does not have to be removed from the furnace all at once. Any part of the load remaining in the furnace after the first piece(s) are quenched, do not see any effective temperature change, given the uniformity described in the aluminum report. Therefore, fluidized bed technology is a very good alternative for titanium heat treating.

Aging temperatures are selected depending on the required strength level in the finished product.

Specific solution and age heat treatments, per MIL-H-81200 are shown in Appendix G.

Annealing

Annealing of titanium alloys serves to increase fracture toughness, ductility at room temperature, dimensional and thermal stability, and creep resistance. There are different annealing treatments for different alloys including: mill annealing, duplex annealing, triplex annealing, recrystallization annealing, and beta annealing. In addition, there is also an additional stabilization anneal to form a stable beta phase in alpha beta alloys, so that there is no transformation of the beta phase to a brittle omega phase. Specific annealing treatments, as specified in MIL-H-81200, are shown in Appendix G.

Stress Relieving

The only factor in the selection of a stress relieving time and temperature is to prevent overaging: temperature must be below at least 25° less than the aging temperature for safety. Specific treatments are shown in Appendix G.

Other Considerations for Heat Treating

Titanium is a reactive metal, especially at elevated temperatures. Hydrogen, nitrogen, and oxygen all embrittle titanium. As a result, MIL-H-81200 allows heat treatment only in inert gas, vacuum, or combusted hydrocarbon atmosphere. However, commercial practice is less flexible: solution treating is typically done in inert gas (newer vacuum furnaces do not have liquid quenching capability) while aging is done in vacuum or inert gas. Fluidized bed heat treating of titanium should only be under inert gas, with a dew point of minus 65°F or lower. Product testing can only be by tensile properties, since hardness does not correlate well to strength for titanium alloys. Required testing is spelled out in Table VII of MIL-H-81200. The specification has sections regarding contamination, rework of contamination, and surface contamination removal.

Magnesium Heat Treating in a Fluidized Bed

Magnesium castings are used in some aerospace applications. Therefore, this section has been added in order to describe the fluidized bed heat treating of this important class of alloys. Common heat treatments for magnesium alloys include annealing, stress relief, and solution treating and aging. Especially for temperatures above 750°F, atmospheric protection is important: the two allowable protective gases employed are carbon dioxide and sulfur dioxide. However, with the stringent emission requirements imposed by the 1990 Clean Air Acts on sulfur dioxide, carbon dioxide appears to be the protective gas of choice. Recommended gas is air with 5% carbon dioxide. As is the case for any application, one of the distinct advantages of fluidized bed technology is the ability to create any desired atmosphere by adjusting the fluidizing gas, and this is especially true for magnesium alloy. Common annealing cycles for magnesium alloys are shown in Appendix H.

The thermal conductivity of magnesium is 83% that of aluminum, and thus, will heat up relatively rapidly as will aluminum. Therefore, the minimum heat up times will mirror those of aluminum: the actual times will be those of aluminum divided by 0.83. These times are reflected in Appendix I.

Heat Treatment of Copper Alloys

Introduction

This report will describe the heat treatment of copper alloys. The various treatments include homogenization, annealing, stress relief, and hardening. There are several mechanisms employed for hardening copper alloys including martensitic type quenching and tempering, solution and aging, spinodal hardening, and order hardening. As with other alloys, there are two components to heat treating: heat treat cycles are shown in Appendix J. Since the thermal conductivity of copper and copper alloys is in between that of aluminum and steel, soak time shall be considered to begin as soon as the lowest reading control thermocouple is at the lower limit of the specified treatment temperature range. Longer soak times may be necessary for forgings. Shorter soak times are satisfactory when soak time is accurately determined from thermocouples attached to the load.

Homogenization

Homogenization is employed primarily on copper castings, where there are no further mill operations performed. This treatment reduces chemical segregation in castings. Typical cycles are 3 to 10 hours at approximately 90°F below solidus temperature. Specific data should be obtained from product manufacturers.

Annealing

Annealing is employed to soften and increase metal ductility. Annealing response will vary according to the amount of prior work, and the heat treatment schedule must be based on this variable.

Stress Relief

Stress relief is employed to relieve internal stresses without affecting grain structure or properties.

Hardening

The majority of hardened alloys are obtained from the solution and aging type heat treatments. Most of the alloys are strengthened from precipitates. Some alloys are strengthened by spinodal decomposition, and a few are strengthened by an ordering reaction.

Other Heat Treating Considerations

Atmosphere generation is a very important heat treating consideration. Oxidation of copper alloys is of primary consideration, especially for the higher temperature treatments. For some hardening treatments literature suggests exothermic or dissociated ammonia work well on copper. Another consideration, is that many applications require bright surfaces. This is best accomplished with mixtures of inert gas and hydrogen, typically Ar-1%H. Nitrogen should be acceptable based on the fact that for other metal treatment, it is often considered to be an inert gas. Fluidized beds can be run with any of these gases.

Aging and stress relieving require especially tight control of ±5°F. This requirement makes fluidized bed equipment an excellent choice for the heat treatment of copper alloys. The only realistic alternative which can exhibit this uniformity -- salt, requires subsequent part cleaning to remove salt accumulations on the surface.

Copper Beryllium Alloys

Copper beryllium alloys are a class of alloys being utilized in aerospace applications. Heat treating of these alloys for military applications is governed by MIL-H-7199. Some of these alloys with high beryllium contents form a tenacious, beryllium-rich scale in unprotected atmospheres. This scale does not affect mechanical properties, but is abrasive and causes extreme wear of tools. It is common for bright heat treating to be specified. Here, the argon - hydrogen atmospheres described earlier are employed for solution treating. The aging treatment is typically performed in the same atmosphere, in vacuum or in dissociated ammonia.

It should be noted that copper beryllium alloys are typically provided in the solution treated condition by the manufacturers. Therefore, a resolution treatment should only

be performed when a joining technique such as welding or brazing or excessive cold work renders the material unsuitable for aging.

Fluidized Bed Furnace Use For Non-Ferrous Alloys

A fluidized bed furnace is a reasonable economic choice for any heat treating process performed at below 2200°F. It offers the advantages of

- rapid heat up rates compared to convective air or gas furnaces.
- lack of hazardous wastes compared to salt baths.
- the ability to create any desired gaseous atmosphere be it inert, reducing, oxidizing, carburizing or other EXCEPT vacuum.

An example would be nickel heat treating. All treatments could be done. Many source books will give all solution and age cycles. Heat up times can be set up in tabular form as was done with aluminum for materials with high thermal conductivities, or based on the time when all control thermocouples are in required range, as was the case for steel, which has a significantly lower thermal conductivity. Finally a decision on the atmosphere would have to be based on the application and production sequence (i.e. is the part at final size or will machining be done after heat treatment). The number of nickel and iron-nickel base alloys is too large for inclusion in this report.

Fluidized Bed Furnaces and Environmental Considerations

Introduction

To fully compare fluidized bed heat treating to conventional heat treating it will be necessary to consider all major methods of conventional heat treating. These methods include molten salt bath, endothermic gas carburizing, inert gas heating, and vacuum.

The MSDS will be used to compare safety considerations including flammability, adverse health, and reactivity ratings. Consideration will be given to atmospheric gases, refractory material, heating media, and fluidized powder.

Discussion

The major materials used in fluidized bed heat treating which require evaluation in regards to environmental soundness include the various gases commonly used, and the ceramic powder used as the heating media. Similarly vacuum heat treating uses various gases, vacuum pump oil, and refractory heating elements. Salt baths use molten salts.

Common gases used in fluidized bed include ammonia, nitrogen, argon, methane, and methanol. Other gases are not normally used by Procedyne. Vacuum furnaces use nitrogen and helium via backfilling for rapid cooling. Refractory heating elements are either graphite or molybdenum disilicide. Finally, molten salt baths employs molten salts consisting of combinations of barium chloride, sodium chloride, and potassium chloride.

At this time the only ceramic powders used by Procedyne in heat treating applications are alumina and alumina-titania blended mixtures. The Material Safety Data Sheet (MSDS) (ref 13) for alumina reveals the following information:

There are no health, flammability, or reactivity dangers, as evidenced by the 0 ratings.

The only health warnings are ingestion and breathing are not recommended and getting the powder in ones eyes may irritate and abrade them.

A German study (ref 14) further expands on the health factors as follows:

Particles used as radiant agent was inert in animal experiments and cellular tests.

Inhaled powder is eliminated by normal processes through the bronchia: long term deposits in the lungs are not expected.

No fibrogenous and carcinogenic effects were found.

One final advantage: parts placed in a fluidized bed carrying surface oil or moisture do not create an explosion risk because the contaminants simply vaporize and are removed with the exhaust gas (ref 15).

Barium containing salts pose a much greater environmental risk. The MSDS (ref 16) shows a health risk of 3, and a flammability rating of 1. The dangers are from decomposition to barium as well as liberated chlorine gas. The greatest health risk is from degradation product -- barium. Soluble barium compounds affect muscles, slow or stop the heart, cause vascular and bladder contraction, and increase voluntary muscle tension. Paralysis or rhabdomyolysis (a potentially fatal disease marked by destruction or degradation of skeletal muscle) can occur. The danger from flammability increases when the material is converted from solid to liquid. When the salt is liquid, the dangers increase from liquid eruptions and splashing, and explosions from humidity. Finally there is a long list of acute effects. The MSDS is displayed in Figure 1. Chlorine gas also displays a health risk of 3. It reacts with body moisture to form HCl. Inhalation can cause asphyxiation. In summary, the use of molten neutral salt baths present risks which can be eliminated by conversion to fluidized beds. One more factor is that the salts cannot be disposed by normal ground dumping.

Fluidized bed and normal atmospheric heat treating both employ various gases to create special environments such as nitrogen, carbon monoxide, hydrogen, ammonia, argon, methanol, and methane. One method is no more or less dangerous depending on the gas used. MSDS's for the various gases (refs 17 & 18), do not assess risk potential for health, flammability of reactivity. However, a Union Carbide publication of Safety Precautions for various gases (ref 19) provides the following generic warnings:

Nitrogen, argon, helium and carbon dioxide can all cause rapid asphyxiation and death if released in confined, poorly ventilated areas. Furthermore, all of these gases, when cold or liquid can cause frostbite, as does liquid oxygen.

Oxygen supports and greatly accelerates combustion. Furthermore, discharging of liquid oxygen should be in remote outdoor pits filled with grease-free and oil-free gravel, to facilitate safe evaporation.

Hydrogen is flammable and will explode if ignited.

Other gas MSDS's illustrate that methane and methanol decomposes to CO/CO_2 which is an asphyxiant. Combustion in the absence of oxygen liberates hydrogen. Methanol is also toxic if ingested, causing CNS depression, severe metabolic acidosis, blindness, and in the worst case death. Finally, physicians are warned to observe victims of overexposure to ammonia for 72 hours for delayed onset of pulmonary edema.

Dangers associated from working with gases can be minimized by provide for proper ventilation, by using proper containers, piping, and valving, by keeping sparks away.

There some other important safety considerations. The first is the lack of hazardous fumes such as carbon monoxide, associated with the opening of carburizing furnaces, because of the combination of the burnoff stack, and finishing the cycle under 100% nitrogen. All CO gas is completely combusted in the stack during carburization, and furthermore is completely purged out by the nitrogen long before the furnace is opened. Most fluidized bed furnaces (all Procedyne furnaces) have additional safety features built in to eliminate the dangers of gases and include:

- double block and vent systems for gas fired furnaces. These systems shut down the flow on a furnace, and any gas trapped between the two block valves is vented to atmosphere.
- gas fired furnaces also have a flame safety system where the furnace is shut down if a UV detector cannot detect a flame. Start up cannot occur until a pre-purge cycle is manually initiated.
- Solenoid valves and pressure switches for low pressure gas, high pressure gas, and low combustion air are built into each train for atmospheric gases, so that if triggered, the gas system shuts down.
- There is a continuous gas pilot in the burnoff stack. If this pilot goes off, the gases are automatically shut down.

In summary, the dangers associated with the use of industrial gases in fluidized beds are no more and no less than using the same gases in more conventional gas atmospheric furnaces. With the additional safety engineering incorporated into fluidized bed furnaces and the process difference of finishing some cycles on nitrogen, the safety risks of the gases are minimized, making the fluidized bed furnace an attractive alternative to conventional furnaces.

Vacuum heat treating is a benign process from an environmental standpoint. Silicon carbide heating elements have 0 ratings for health, flammability, and reactivity (ref 20). Vacuum oil has a risk rating of 1 for flammability, since it is a hydrocarbon (ref 21). The design of these pumps virtually eliminates any risk of flammability (which would also liberate CO gas), because they operate at well under 200°F. The most common gases used in vacuum heat treating are argon, helium, and nitrogen particularly for cooling. Under special circumstances (such as special vacuum sintering cycles), hydrogen, ammonia, carbon dioxide, and carbon monoxide MIGHT be used in one or more stages of a vacuum process. As an example, hydrogen might be used during the heat up of a sintering cycle to reduce any surface oxides on individual powder particles.

CONCLUSIONS

Molten salt baths are quite hazardous from the standpoint of health and flammability hazards. Selection of fluidized beds as an alternative is an environmentally sound decision.

Environmentally, fluidized beds, vacuum furnaces, and gas atmosphere furnaces all have potential hazards ONLY FROM THE GASES USED FROM EACH PROCESS. Atmospheric furnaces are at a disadvantage to fluidized bed and vacuum because of the liberation of carbon monoxide fumes when the furnace is open. The rest of the safety features described have to be evaluated on a vendor by vendor basis. because there is no guarantee that every vendor uses these safeguards that Procedyne uses.

Clean Air Act Considerations

Volatile Emissions (VOC's)

Per the Clean Air Act of 1990 (ref 22), the maximum allowable level of volatile organic compound emission (VOC) is 50 tons per year. A recent monitoring of the Procedyne 1836 HT2050 furnace found a zero VOC or non combusted fuel level, (measured by Air Products Corporation).

NOx

The same Clean Air Act, permits a maximum allowable level of NOx emission at 100 tons per year. During the above trial, NOx emission level was 5 ppm. Translating this into some real numbers, this means the following:

- For a 2448 furnace (the most typical size for commercial carburizing), with a fluidization rate of 1000 scfh, 0.005 cubic feet per hour of NO2 would be generated. In the worst case scenario, the furnace runs 3 shifts per day, 7 days per week, 50 weeks per year. This translates to a total NOx level of 42 cubic feet per year. Obviously this is nowhere near the 100 ton level, in fact it is only 4 pounds. Even if the level were 5 times as high, (the temperature at the point just above the tip of the burnoff flame where emissions were measured was 195°F), the total emissions are only 20 pounds

These experiments were performed by Air Products Corporation on Procedyne's 1430 HT2050 fluidized bed heat treating furnace.

These number back up the literature claims that fluidized bed furnaces are excellent choices for heat treating in a manner consistent with the requirements of the Clean Air Act of 1990. The key for compliance, is the use of a PROPER burn off stack, ensuring complete combustion of fuel. These stacks are custom made for each furnace and application.

Cost Comparisons of Fluidized Bed vs. Traditional Process

Assumptions and Bases

- Electric heating is assume to be 90% efficient.
- Gas firing efficiencies will vary based on temperature and type of burner. This study uses the following efficiencies:
    - 25% at 1700, with non recuperative burners.
    - 33% at 1550, with non recuperative burners.
    - 66% at 1700, with recuperative burners.
    - 75% at 1550, with recuperative burners.
- Fluidizing gas costs directly from vendors.
    - Methanol per gallon: $1.20
    - Liquid nitrogen per ccf: $0.60
    - Natural gas per ccf: $0.66
    - Ammonia per ccf: $2.17
- Electricity costs are $0.094 per kwh.
- During heat up, the power demand will be 100%: once steady state temperature is reached, the demand will drop off to 33%.
- Heat treated parts will be high quality: there will be a specification for surface carbon concentration.

Carburization

Traditional gas carburizing

- Furnace needs 125 kw (ref 23). This translates to 450 kJ per hour, and 4.26 therms. The costs for heat up and soaking per hour are as follows:

		1700°F Gas		*1550°F Gas*	
	Electric	*No Recoup.*	*Recoup.*	*No Recoup.*	*Recoup.*
Energy Required	125 kw	17.04 Therm	6.39 Th.	12.78 Therm	5.68 T
Heat Up Cost/hr.	$13.24	$11.18	$4.17	$8.33	$3.70
Soak Cost/hr	$3.31	$2.79	$1.04	$2.08	$0.93

  For this example, assume best case of gas recoup.
- Traditional gas carburizing also requires endothermic gas generation. A typical endothermic gas generator (ref 24) will require a heat input of 7.97 therms per hour, for a cost of $4.94 per hour. Furthermore, the material must be cooled for at least 2 hours in an antechamber with an endo atmosphere, to a temperature low enough that decarburization will not take place.
- Salt bath needs 140 kw. For electric this translates to 155.6 kw input or 14.54. With an operating temperature of 1550°F, the corresponding gas requirement is 4.78 therms per hour, costing $9.35 OR 4.15 with recuperator burners.
- The heaviest cross sectional dimension will be set at 2", so the soak time per MIL-H-6875 is 20 minutes (assume no temperature drop in the salt).

Process:	Cycle Time	Gas Cost
Load Recovery	1 hr.	$ 13.67
Carburize	3.5 hr.	31.92
Cool Down in Antechamber	4 hr.	19.76
Salt Bath Reheat	1 hr.	4.15
Total	9.5 Hours	$ 69.50

Cost per Pound 800 # (same as fluidized bed MAX) $0.085
1200# (Max size for these furnaces) $0.058

Fluidized Bed Carburizing

Assumptions

Carburizing performed in a 2448 furnace (24"∅ x 48" deep) electrically heated furnace.
The maximum power rating is 96 kw.
Fluidization Flow Rate is 1000 scfh
Carbon Potential During Boost = 1.6%

Process	Cycle Time	Electric		N2		MeOH		Nat. Gas	
Recovery	1 hr	96 kw	$8.98	10 ccf	$6.00	--------		-----------	
Boost	40 min	21.3	1.99	2.5	1.5	4 ccf	$4.60	20 scf	$0.13
Diffuse	110 min	58.4	5.46	18.3	10.98	--------		-----------	
Cool Down	60 min	----------		10	6.00	--------		-----------	
Totals	4 1/2 hr.	$16.43			$24.48		$4.60		$0.13

Total Cost = $45.64
Cost per pound (800 pound max load) $0.057

Nitriding

Basis of Comparison 0.014" Case on 4130/H13 Steel

Traditional Nitriding[25]

Process		Cycle Time	Power Usage		Ammonia Usage	
Purging		1.5 hr	0		2.25 ccf	$4.88
Heat Up		3	300 kwh	$28.05	1.8	3.91
Nitride 4130		32	800	74.80	19.2	41.66
Nitride H13		48	1200	112.20	28.89	62.50
Cooling #1		2	0		3.0	6.51
Cooling #2		7	0	0		
Total	4130	45.5	1100 kwh	$102.85	26.3	$57.06
	H13	61.5	1500	140.25	35.9	$77.90

Assumptions

Using a charge weight of 2950 pounds:
4130 Total Cost is $159.91 or $0.054/#
H13 Total Cost is $218.15 or $0.074/#

Fluidized Bed Nitriding

Process	Cycle Time	Power Usage		Nitrogen		Ammonia	
Lower Temp	.5	0		6.3	$3.78	0	
-or-							
Recover	1	96 kw	$8.98	10	$6.00	0	
Nitride 4130	10	240	22.44	18	10.80	12	$26.04
Diffuse 4130	5	120	11.22	60	36.00	0	
Nitride H13	13	312	29.17	23.4	14.04	15.6	33.85
Diffuse H13	6.5	156	14.59	81.25	48.75	0	
Total 4130	15.5	360	$33.36	78	$46.80	12	$26.04
Temper A	16	456	42.64	78	$46.80	12	$26.04
H13	20	468	43.76	104.7	$62.82	15.6	$33.85
Temper A	20.5	552	51.61	104.7	$62.82	15.6	33.85

Total Costs	4130	$106.20 or $0.042/#
	4130 Temper A	$115.48 or $0.046/#
	H13	$140.43 or $0.056/#
	H13 Temper A	$148.28 or $0.059/#

Assumptions

Use a charge weight of 2500 #
Fluidization is 1200 scfh
During Nitriding using Procedyne™ Low Flow Process, Fluidization is 300 scfh
Typical Process Entails Lowering Furnace after completion of tempering.
Temper A is the alternative of Nitriding at a Later Time.

Neutral Hardening and Aging

Case 1 1200 pound Load Steel Temper @ 1000°F/1" Max Cross Section

	Fluidized Bed 2448	*Atmosphere Box Furnace*
Maximum Power	65 kw	36 kw
Soak Power (33% Max)	22 kw	12 kw
Heat Up Time	1.5 hr.	3 hr.
Temper Time	2 hr.	2 hr.
Total power to Heat Up	97.5 kwh	108 kwh
Total power for soak	44 kwh	24 kwh
Total power	141.5 kwh	132 kwh
Total cost	13.23	12.34
Cost per pound	0.011	0.010
Cycle Time	3.5 hr	5 hr
Per day capacity	7 loads	5 loads (4.8)

For the case of steel tempering, unit costs are slightly higher (0.1 cents per pound) for the fluidized bed. However, 2 additional loads per day can be processed. Therefore, the decision between fluidized bed vs. traditional temper is a tradeoff between unit cost

daily capacity, and whether the added revenue from the extra load offsets the added heating cost.

Case 2 100 pounds of aluminum castings, alloy 356 solution treat.

	Fluidized Bed 2448	*Atmosphere Box Furnace*
Maximum Power	65 kw	36 kw
Soak Power (33% Max)	22 kw	12 kw
Heat Up Time	0.5 hr.	2 hr.
Solution Time	12 hr.	12 hr.
Total power to Heat Up	32.5 kwh	72 kwh
Total power for soak	264 kwh	144 kwh
Total power	296.5 kwh	216 kwh
Total cost	27.72	20.20
Cost per pound	0.28	0.20
Cycle Time	12.5 hr	14 hr
Per week capacity *	9 loads (9.6 actual)	8 loads (8.6 actual)

* assumes 5 day week, 24 hours per day.

In this case, the box furnace is significantly more economical, but again the fluidized bed will yield one additional load per week due to the heat up time. So once again, the decision will be a trade off between throughput, and cost per pound. This scenario is based on single layer loading. A difference in unit cost decreases as the weight of the charge increases. The recovery times will increase with load size, and have to be determined accordingly. Again, the decision on which technology to use depends on whether the extra revenue from the extra load offsets the added operating costs.

CONCLUSIONS

Fluidized bed furnaces represent a cost effective alternative to conventional heat treating methods with more safety features with respect to gas line shut downs in emergency situations. There are no hazardous wastes to dispose of unlike salt baths. It is also an attractive alternative when considering compliance with the Clean Air Act of 1990. Finally, because atmospheres are always purged with nitrogen before opening to atmosphere, there are never any irritating, hazardous fumes from either carbon monoxide or ammonia.

In addition, the heat transfer coefficient in fluidized beds are double those from forced convection air furnaces, thus heat up rates can be cut by 50% or more. With the ability to completely change atmospheres within the furnace in 2 minutes or less, multiple operations can be performed in one cycle, rather than 2 to 3 cycles in 2 to 3 different furnaces. Finally, with better uniformity than conventional furnaces, more uniform properties are obtained from run to run (i.e. better statistical control and higher CpK's can be obtained).

Fluidized beds are most economical for high temperature, short cycle heat treating. This is because even when the fluidized beds operate with higher power inputs, the heat up segment is where the majority of the cost is. The higher transfer coefficient found in fluidized bed reduces heat up time by 50%, and that is enough to make the fluidized bed a more economical choice. The cost differences are even more favorable to fluidized

beds, when multiple processes can be done in one furnace one after another, instead of two or three furnaces with cool down and heat up in each furnace, which is the traditional method. As treatment time increases, the percent of the heat up cycle cost in relation to the entire cost is small, and traditional methods are less expensive on a per pound basis. Even in this case, there is a small productivity improvement (one load per week), and the increase revenue must be compared to the additional operating costs in order to make a sound economic decision.

Fluidized bed furnace technology is gaining more acceptance as a heat treating option, and with all the advantages listed, should be considered for most heat treating equipment purchases.

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Appendix A:

Handbook of Neutral Processing of Ferrous Alloys

Appendix A

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PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: A2
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.00 C, 1.00 Mo, 5.00 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

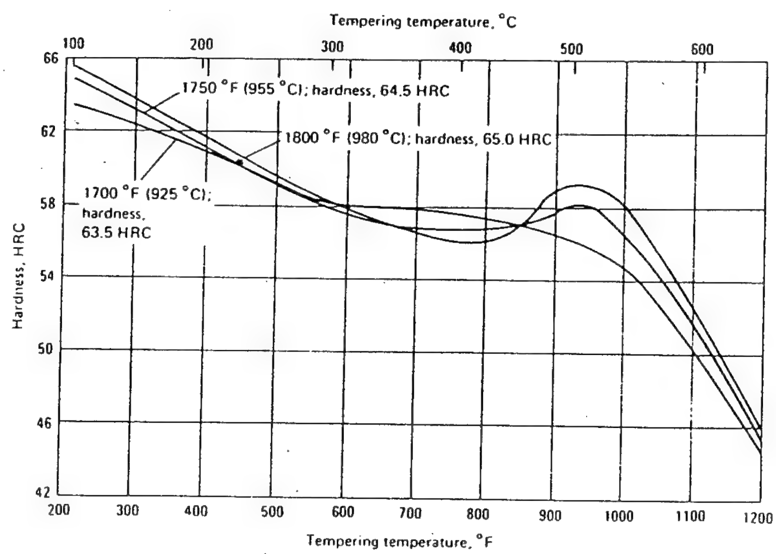
PROCESS:	Neutral Hardening
1ST PREHEAT:	1450°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1700 to 1800°F (20 to 45 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 65 - Temper immediately, after quench, to prevent cracking (do not allow part to cool below 140°F) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

changes in section size. Temper immediately after tool reaches room temperature

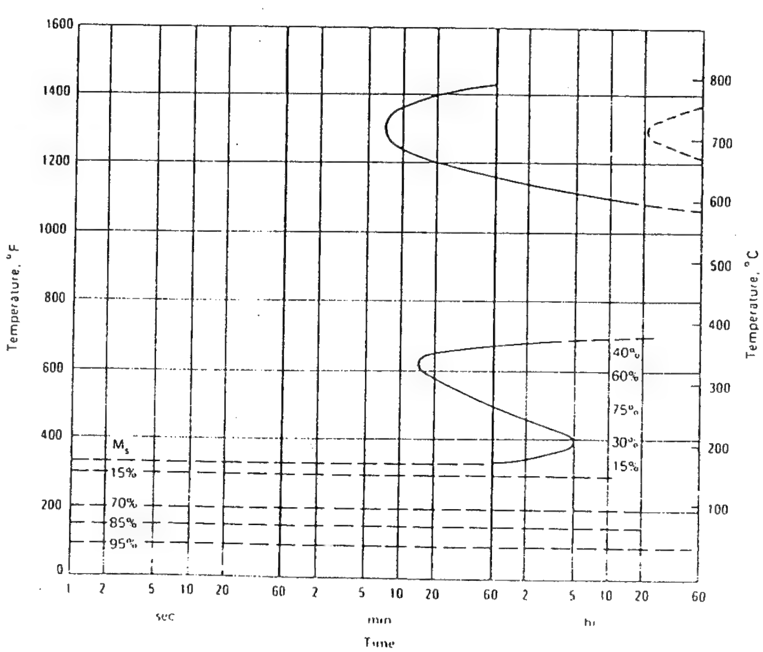
Tempering. Temper immediately at 350 to 1000 °F (175 to 540 °C) after tool has cooled to 120 to 150 °F (50 to 65 °C). Double temper, allowing tool to cool to room temperature before second temper. Range of hardness after tempering, 62 to 57 HRC. Tempering between 350 to 450 °F (175 to 230 °C) is recommended for maximum wear resistance, and between 700 to 750 °F (370 to 400 °C) for maximum shock resistance

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper/double temper
- Final grind



A2: Hardness Versus Tempering Temperature. Austenitized at various temperatures and air cooled. (Source: Universal-Cyclops)



A2: Isothermal Transformation Diagram. Composition: 0.97 C, 0.48 Mn, 0.40 Si, 4.58 Cr, 1.04 Mo, and 0.25 V. Prior condition, annealed. Austenitizing temperature, 1850 °F (1010 °C). (Source: The Hardening of Tool Steels, by P. Payson and J. L. Klein: in *Transactions of the American Society for Metals*, Vol 31, No. 1, March 1943)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: A3
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.25 C, 1.00 Mo, 5.00 Cr, 1.00 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

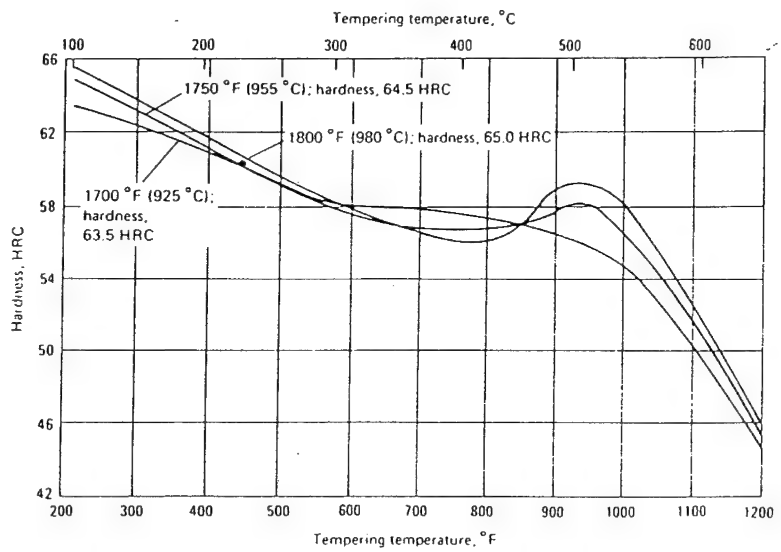
PROCESS:	Neutral Hardening
1ST PREHEAT:	1450°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1750 to 1850°F (25 to 60 minutes, depending on cross section) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 65 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Tempering parameters for A2 are applicable, (approx.) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

changes in section size. Temper immediately after tool reaches room temperature

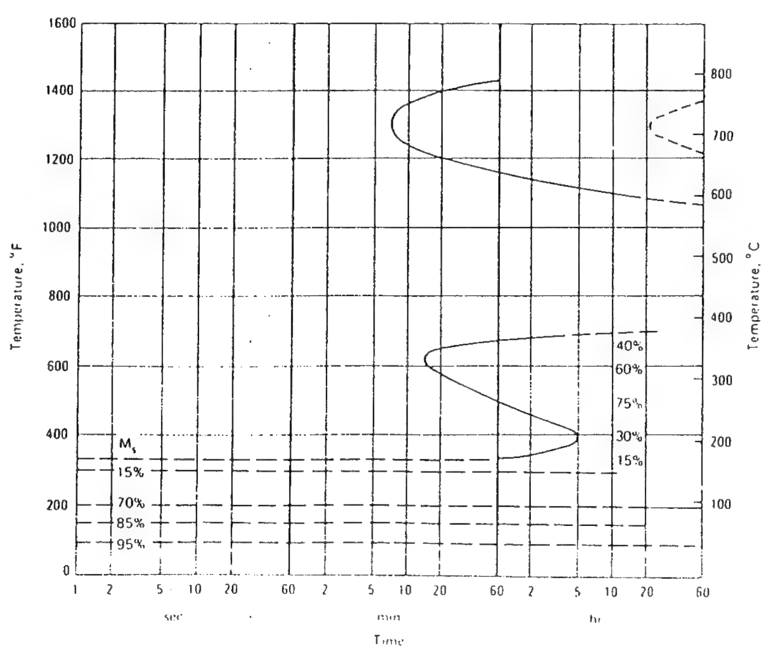
Tempering. Temper immediately at 350 to 1000 °F (175 to 540 °C) after tool has cooled to 120 to 150 °F (50 to 65 °C). Double temper, allowing tool to cool to room temperature before second temper. Range of hardness after tempering, 62 to 57 HRC. Tempering between 350 to 450 °F (175 to 230 °C) is recommended for maximum wear resistance, and between 700 to 750 °F (370 to 400 °C) for maximum shock resistance

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper/double temper
- Final grind



A2: Hardness Versus Tempering Temperature. Austenitized at various temperatures and air cooled. (Source: Universal-Cyclops)



A2: Isothermal Transformation Diagram. Composition: 0.97 C, 0.48 Mn, 0.40 Si, 4.58 Cr, 1.04 Mo, and 0.25 V. Prior condition, annealed. Austenitizing temperature, 1850 °F (1010 °C). (Source: The Hardening of Tool Steels, by P. Payson and J. L. Klein: in *Transactions of the American Society for Metals*, Vol 31, No. 1, March 1943)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: A4
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.00 C, 2.00 Mn, 1.00 Mo, 1.00 Cr

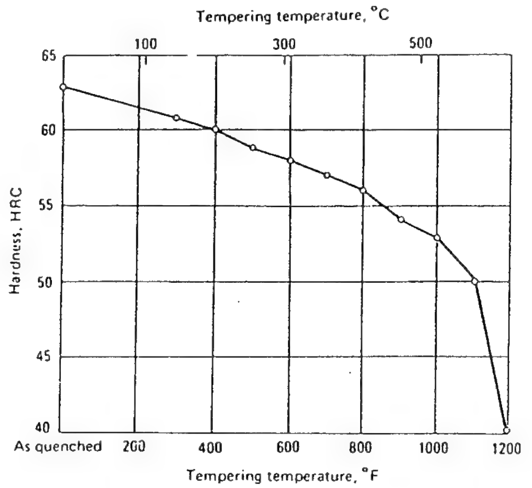
PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1250°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1500 to 1600°F (15 to 90 minutes, depending on cross section) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 61 to 64 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

Tempering. Temper immediately at 350 to 800 °F (175 to 425 °C) after tool has cooled to 120 to 150 °F (50 to 65 °C). Double temper, allowing tool to cool to room temperature before second temper. Range of hardness after tempering, 62 to 54 HRC

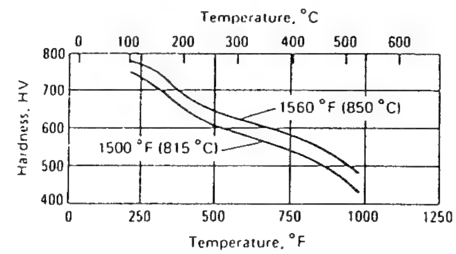
A4: Hardness Versus Tempering Temperature. Austenitized at 1550 °F (845 °C) and cooled in air. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper/double temper
- Final grind

A4: Hardness Versus Tempering Temperature. Austenitized at 1500 °F (815 °C) and at 1560 °F (850 °C) and cooled in air. Data represent upper and lower limits of hardness. (Source: *Tool Steels*, American Society for Metals, 1980)



A6

Chemical Composition. AISI: Nominal. 0.70 C, 2.00 Mn, 1.25 Mo, 1.00 Cr. **UNS:** 0.65 to 0.75 C, 0.90 to 1.20 Cr, 1.80 to 2.50 Mn, 0.90 to 1.40 Mo, 0.030 P max, 0.030 S max, 0.50 Si max

Similar Steels (U. S. and/or Foreign). UNS T30106; ASTM A681 (A-6); FED QQ-T-570 (A-6)

Characteristics. Has properties roughly similar to A4 but with lower carbon content. Among the lowest in distortion in heat treating. Deep hardening, with high safety in hardening. Medium resistance to softening at elevated temperature, and medium to high resistance to decarburization

Forging. Heat slowly. Start forging at 1900 to 2050 °F (1040 to 1120 °C), and do not forge below 1600 °F (870 °C)

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat slowly and uniformly to 1350 to 1375 °F (730 to 745 °C). Soak adequately for section size. Restrict cooling to a maximum rate of 25 °F (15 °C) per hour down to 1000 °F (540 °C), after which faster cooling can be tolerated. Typical annealed hardness, 217 to 248 HB

Stress Relieving. Optional. Heat to 1250 to 1300 °F (675 to 705 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Heat slowly. Preheat to 1200 °F (650 °C). Austenitize at 1525 to 1600 °F (830 to 870 °C). Hold at temperature 20 min for small tools and 45 min for large tools. Air quench. Typical quenched hardness, 59 to 63 HRC

Stabilizing. Optional. Low temperature treatment may increase hardness and improve dimensional stability by reducing the amount of retained austenite, particularly when temperatures at the upper end of the austenitizing range are used. It is safer and definitely recommended to stress relieve temper at 300 to 320 °F (150 to 160 °C) for a short period before refrigerating at −120 °F (−85 °C), particularly for intricate shapes or tools having abrupt changes in section size. Temper immediately after tool reaches room temperature

Tempering. Temper immediately at 300 to 800 °F (150 to 425 °C) after tool has cooled to 120 to 150 °F (50 to 65 °C). Double temper, allowing tool to cool to room temperature before second temper. Range of hardness after tempering, 60 to 54 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper/double temper
- Final grind

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

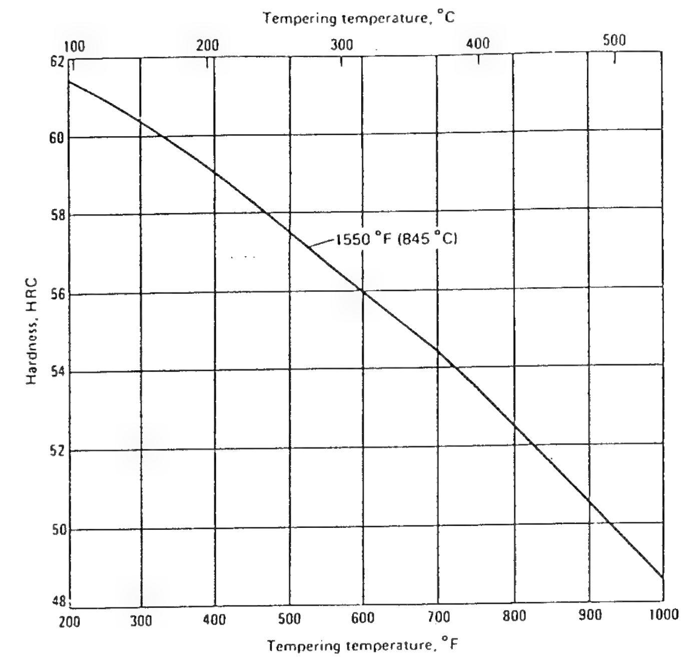
HEAT TREAT DATA SHEET

TYPE OF STEEL: A6
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.70 C, 2.00 Mn, 1.25 Mo, 1.00 Cr

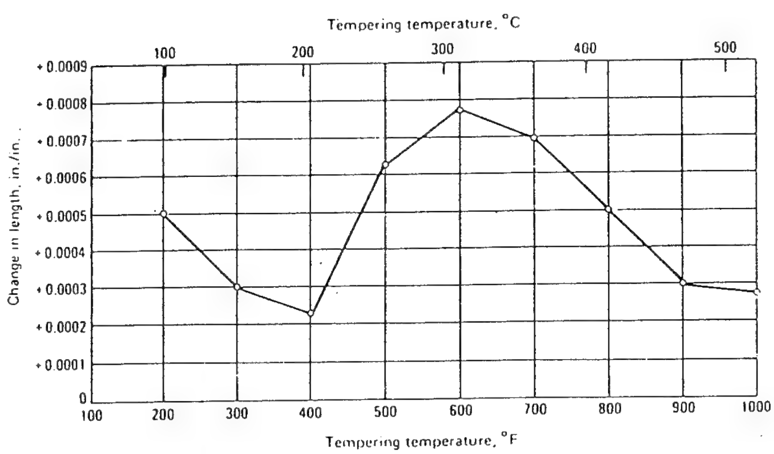
PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

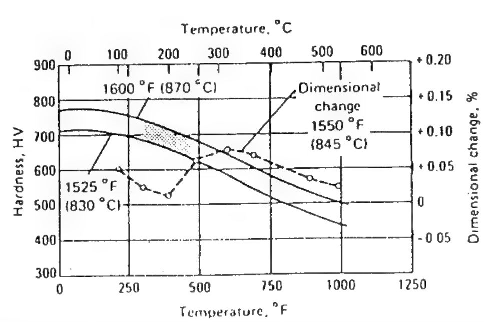
PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1525 to 1600°F (20 to 45 minutes, depending on cross section) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 59 to 63 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper



A6: Hardness Versus Tempering Temperature. Austenitized at 1550 °F (845 °C) and air cooled. Hardness, 62 HRC. (Source: Universal-Cyclops)



A6: Length Changes Versus Tempering Temperature. Austenitized at 1550 °F (845 °C) and air cooled. (Sources: Allegheny Ludlum Industries and Carpenter Steel)



A6: Tempering Characteristics Versus Dimensional Change. Austenitized at 1525 °F (830 °C) and 1600 °F (870 °C) and air cooled, showing upper and lower limits of hardness. Dimensional changes, austenitized at 1500 °F (845 °C) and air cooled. Shaded portion indicates optimum tempering range which coincides with lowest dimensional change. (Sources: *Tool Steels*, 3rd ed., American Society for Metals, 1962, and Carpenter Steel)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

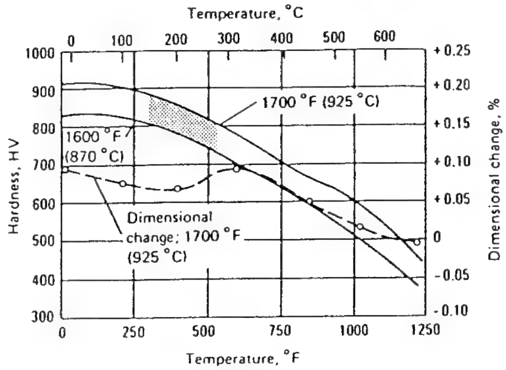
TYPE OF STEEL: **A7**
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)
CHEMICAL COMPOSITION: AISI: Nominal. 2.25 C, 1.00 Mo, 5.25 Cr, 4.75 V, (1.00 W, option.)

PART PREPARATION/FIXTURING:

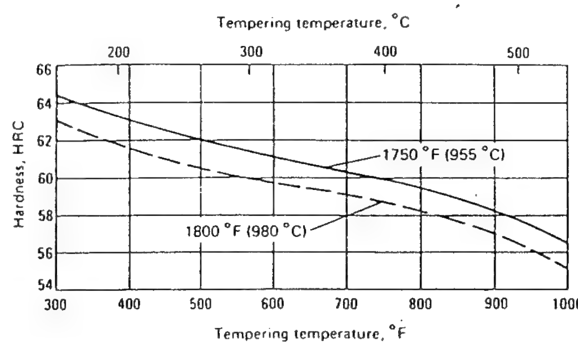
PROCESS PARAMETERS:

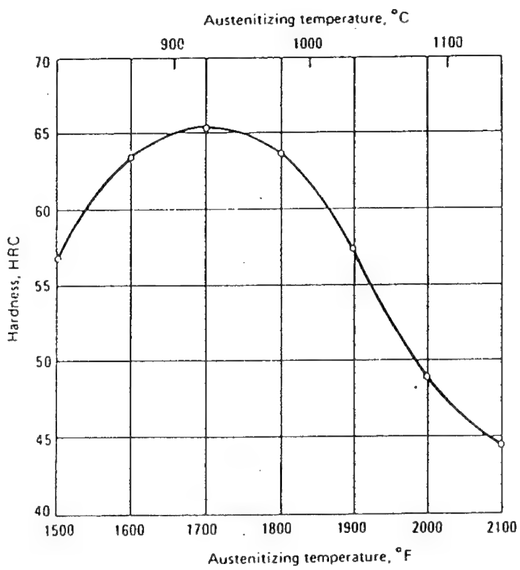
PROCESS:	Neutral Hardening
1ST PREHEAT:	1500°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1750 to 1800°F (30 to 60 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 64 to 67 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

A7: Tempering Characteristics Versus Dimensional Change. Austenitized at 1600 °F (870 °C) and 1700 °F (925 °C) and air cooled, showing upper and lower limits of hardness. Dimensional changes for A7 tool steel, austenitized at 1700 °F (925 °C) and air cooled. Shaded portion shows optimum range which coincides with lowest dimensional change. (Source: *Tool Steels*, American Society for Metals, 1980)



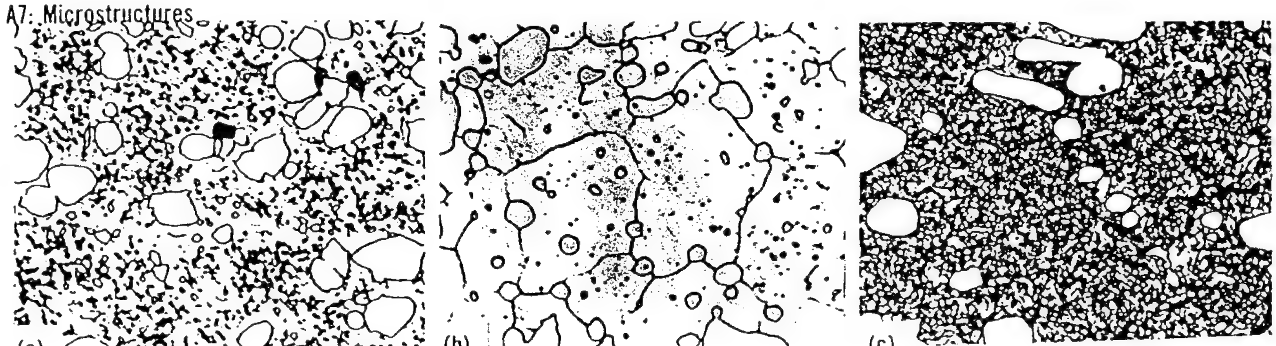
A7: Hardness Versus Tempering Temperature. ½-in. plate austenitized at 1750 °F (955 °C) and air cooled. Hardness, 67 HRC 3-in. cubes austenitized at 1800 °F (980 °C) and oil quenched. Hardness, 66 HRC. (Source: Universal-Cyclops)





A7: Austenitizing Temperature Versus As-quenched Hardness Composition: 2.30 C, 0.40 Si, 0.70 Mn, 1.10 W, 1.10 Mo, 5.25 Cr and 4.75 V, air quenched. (Source: *Tool Steels*, American Society for Metals, 1980)

A7: Microstructures



(a) 4% nital, 1000X. Box annealed at 1650 °F (900 °C) for 1 hr per inch of container thickness and cooled at no higher than 50 °F (25 °C) per hour. Structure massive alloy carbide and spheroidal carbide in a ferrite matrix. (b) 4% nital, 1000X. Austenitized at 1750 °F (955 °C), air cooled, tempered at 300 °F (150 °C). Structure massive alloy carbide (white areas) and a few spheroidal carbide particles in matrix of tempered martensite. (c) 4% nital, 1000X. Austenitized at 1750 °F (955 °C), air cooled, tempered at 600 °F (315 °C). Structure massive alloy carbide and a few spheroidal carbide particles in matrix of tempered martensite. (Source: *Metals Handbook*, 8th ed., Vol 7, American Society for Metals, 1972)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **A8**
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)

CHEMICAL COMPOSITION: AISI: Nominal. 0.55 C, 1.25 W, 1.25 Mo, 5.00 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

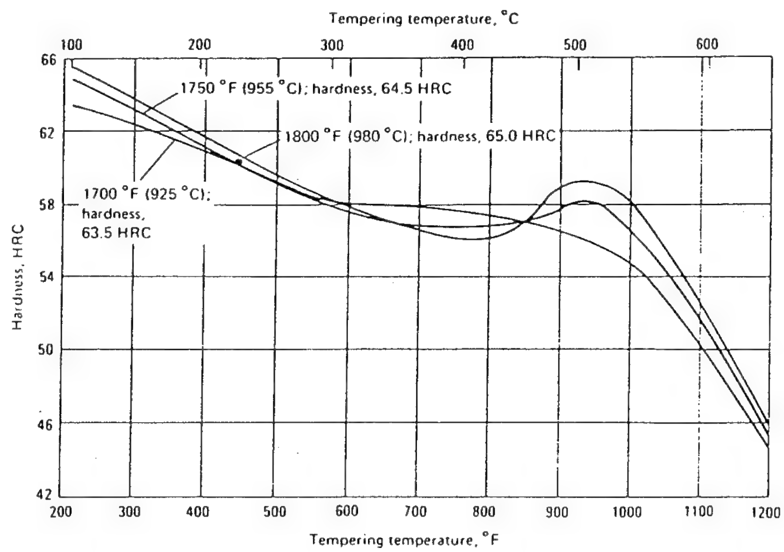
PROCESS:	Neutral Hardening
1ST PREHEAT:	1450°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1800 to 1850°F (20 to 45 minutes, depending on cross section) note: *time at temp.*
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 60 to 62 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Tempering parameters for A2 are applicable, (approx.) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

changes in section size. Temper immediately after tool reaches room temperature

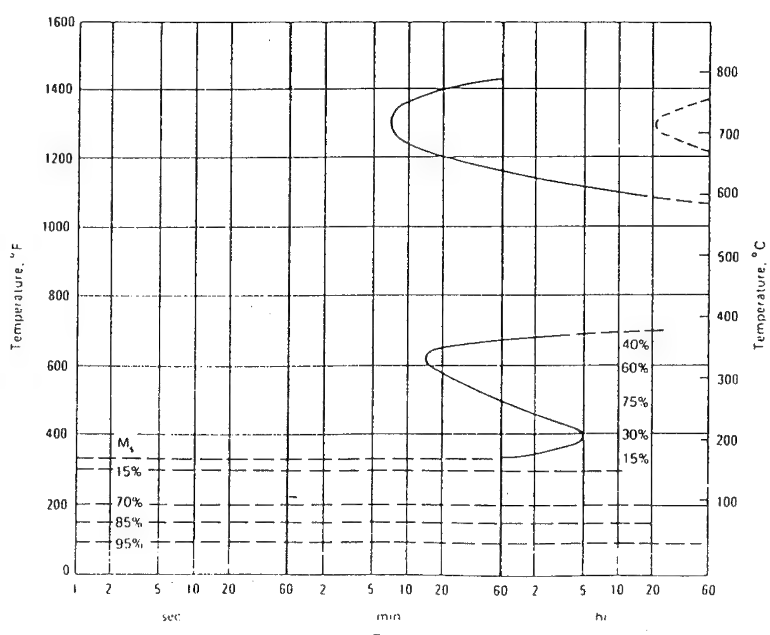
Tempering. Temper immediately at 350 to 1000 °F (175 to 540 °C) after tool has cooled to 120 to 150 °F (50 to 65 °C). Double temper, allowing tool to cool to room temperature before second temper. Range of hardness after tempering, 62 to 57 HRC. Tempering between 350 to 450 °F (175 to 230 °C) is recommended for maximum wear resistance, and between 700 to 750 °F (370 to 400 °C) for maximum shock resistance

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper/double temper
- Final grind



A2: Hardness Versus Tempering Temperature. Austenitized at various temperatures and air cooled. (Source: Universal-Cyclops)



A2: Isothermal Transformation Diagram. Composition: 0.97 C, 0.48 Mn, 0.40 Si, 4.58 Cr, 1.04 Mo, and 0.25 V. Prior condition, annealed. Austenitizing temperature, 1850 °F (1010 °C). (Source: The Hardening of Tool Steels, by P. Payson and J. L. Klein: in *Transactions of the American Society for Metals*, Vol 31, No. 1, March 1943)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **A9**
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.50 C, 1.40 Mo, 5.00 Cr, 1.00 V, 1.50 Ni

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1450°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1800 to 1875°F (20 to 45 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 56 to 58 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

A9

Chemical Composition. **AISI:** Nominal. 0.50 C, 1.40 Mo, 5.00 Cr, 1.00 V, 1.50 Ni. **UNS:** 0.45 to 0.55 C, 4.75 to 5.50 Cr, 0.50 Mn max, 1.30 to 1.80 Mo, 1.25 to 1.75 Ni, 0.030 P max, 0.030 S max, 0.95 to 1.15 Si, 0.80 to 1.40 V

Similar Steels (U. S. and/or Foreign). UNS T30109; ASTM A681 (A-9); FED QQ-T-570 (A-9)

Characteristics. Similar to A8 in low carbon content, but with slightly higher alloy content. Marked secondary hardening characteristics and usually tempered in the 950 to 1150 °F (510 to 620 °C) range. High in resistance to softening at elevated temperatures, deep hardening, and very low in distortion. Among the highest in safety in hardening, with medium resistance to decarburization

Forging. Heat slowly. Preheat at 1200 to 1250 °F (650 to 675 °C). Start forging at 1950 to 2100 °F (1065 to 1150 °C), and do not forge below 1700 °F (925 °C)

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat slowly and uniformly to 1550 to 1600 °F (845 to 870 °C). Soak adequately for section size. Restrict cooling to a maximum rate of 25 °F (15 °C) per hour until 1000 °F (540 °C) is reached, after which cooling rate is not critical. Typical annealed hardness, 212 to 248 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

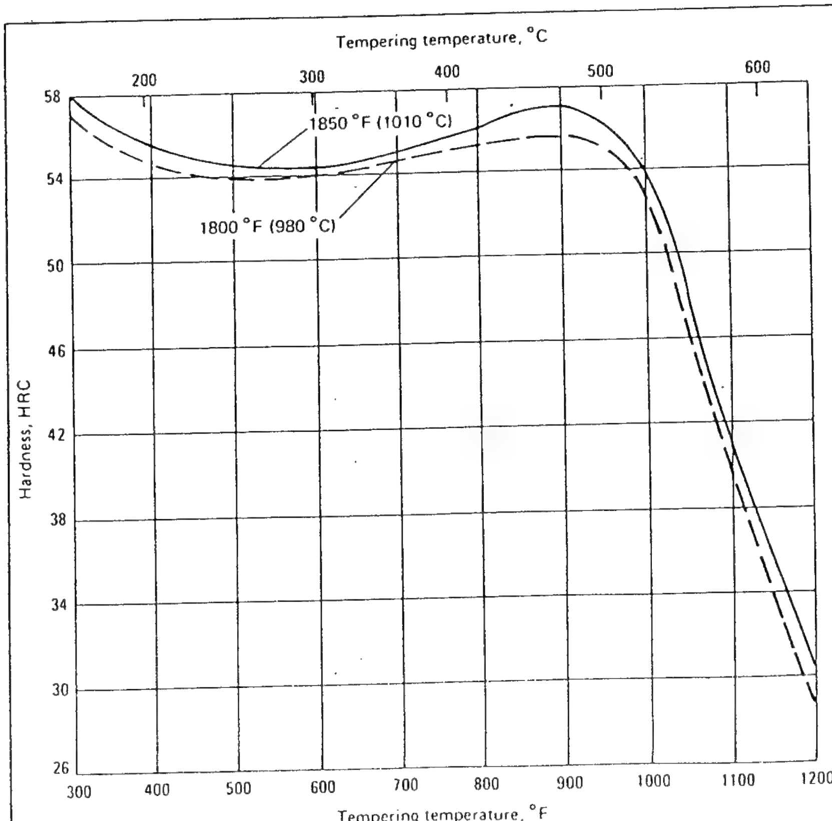
Hardening. Heat slowly. Preheat at 1450 °F (790 °C). Austenitize at 1800 to 1875 °F (980 to 1025 °C) and hold at temperature for 20 min for small tools and 45 min for large tools. Air quench. Typical hardness, 56 to 58 HRC

Stabilizing. Optional. Low temperature treatment may increase hardness and improve dimensional stability by reducing the amount of retained austenite, particularly when temperatures at the upper end of the austenitizing range are used. It is safer and definitely recommended to stress relieve temper at 300 to 320 °F (150 to 160 °C) for a short period before refrigerating at −120 °F (−85 °C), particularly for intricate shapes or tools having abrupt changes in section size. Temper immediately after tool reaches room temperature

Tempering. Temper immediately at 950 to 1150 °F (510 to 620 °C) after tool has cooled to 120 to 150 °F (50 to 65 °C). Double temper, allowing tool to cool to room temperature before second temper. Range of hardness after tempering, 56 to 35 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper/double temper
- Final grind



A9: Tempering Temperature Versus Hardness. Austenitized at 1800 °F (980 °C) and 1850 °F (1010 °C) and cooled in air. (Source: Universal-Cyclops)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: A10
Medium Alloy, Air Hardening Cold Work Tool Steel (A Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.35 C, 1.80 Mn, 1.25 Si, 1.50 Mo, 1.80 Ni

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1450 to 1500°F (30 to 60 minutes, depending on cross section) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	350 to 800°F for approx. hardness of HRC 62 to 55 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 64 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

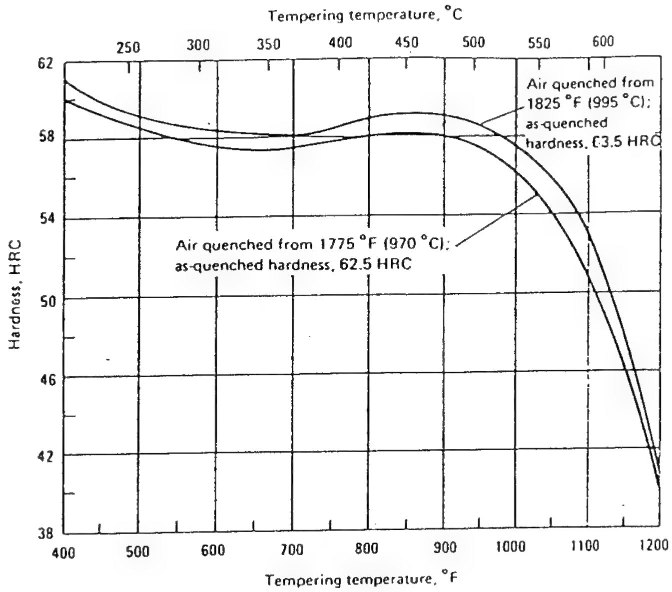
HEAT TREAT DATA SHEET

TYPE OF STEEL: D2
High Carbon, High Chromium Cold Work Tool Steel (D Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.50 C, 1.00 Mo, 12.00 Cr, 1.00 V

PART PREPARATION/FIXTURING:

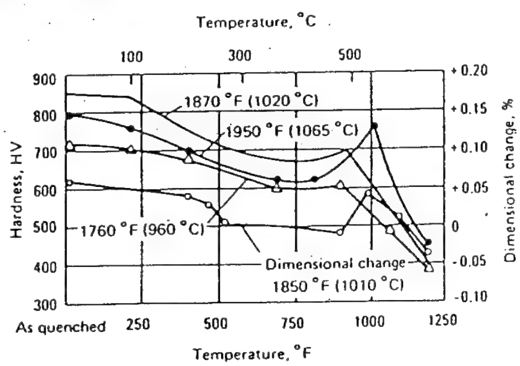
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1500°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1800 to 1875°F (15 to 45 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	1000°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 64 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

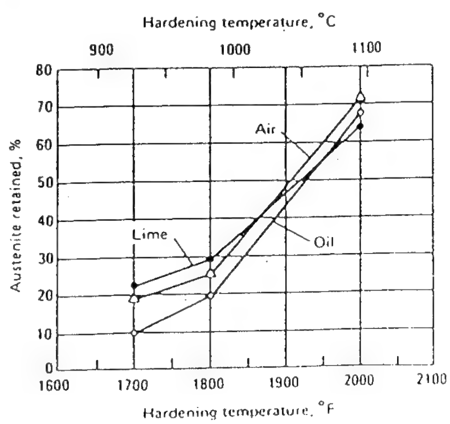


D2: Hardness Versus Tempering Temperature. Austenitized at 1775 °F (970 °C) and 1825 °F (995 °C) then air quenched. (Source: Universal-Cyclops)

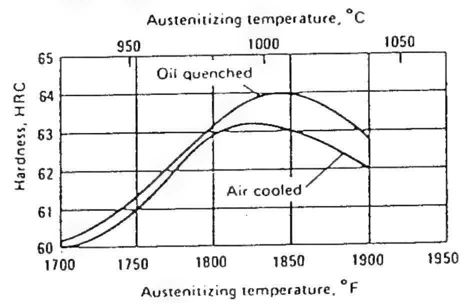
D2: Tempering Temperature Versus Dimensional Change. Swedish grade austenitized at two different temperatures. Dimensional change for a similar steel austenitized at a slightly lower temperature. (Source: Uddeholm and Carpenter Steel)



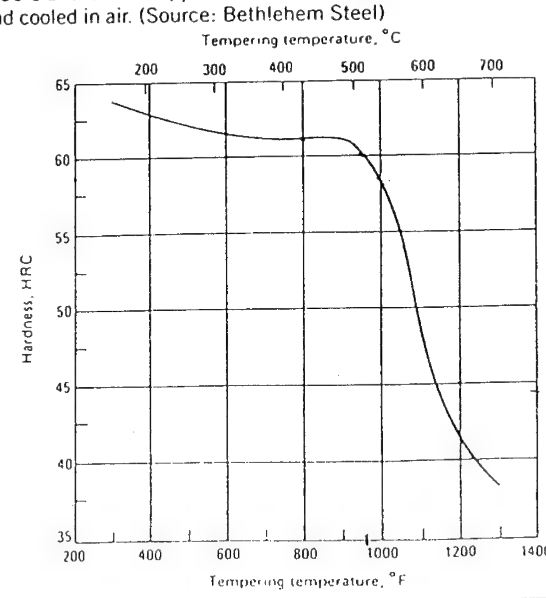
D2: Austenitizing Temperature Versus Retained Austenite. Composition: 1.60 C, 0.33 Mn, 0.32 Si, 11.95 Cr, 0.25 V, 0.79 Mo, 0.010 S, 0.018 P, when quenched in lime, air and oil. (Source: *Tool Steels*, American Society for Metals, 1980)



D2: As-quenched Hardness. Effect of quenching medium and austenitizing temperature on as-quenched hardness of a D2 tool steel containing 1.50 C. (Source: *Tool Steels*, American Society for Metals, 1980)



D2: Hardness Versus Tempering Temperature. Composition: 1.50 C and 12.00 Cr; pack hardened at 1850 °F (1010 °C) and cooled in air. (Source: Bethlehem Steel)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

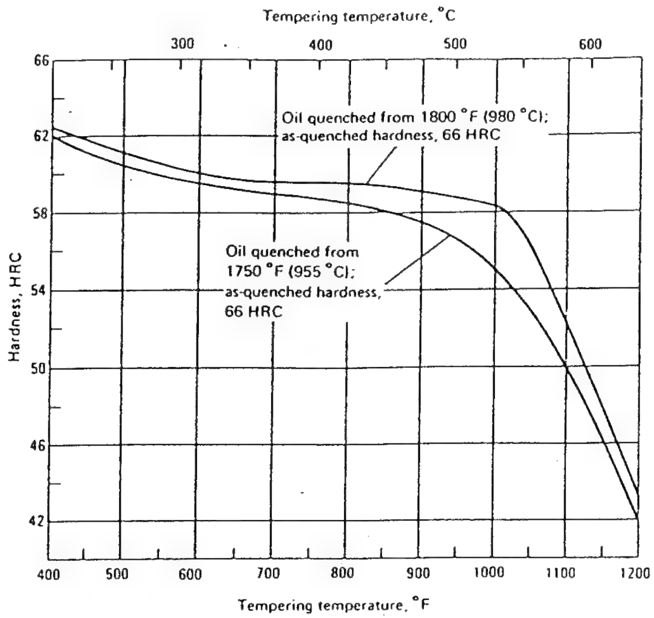
HEAT TREAT DATA SHEET

TYPE OF STEEL: **D3**
High Carbon, High Chromium Cold Work Tool Steel (D Series)
CHEMICAL COMPOSITION: AISI: Nominal. 2.25 C, 12.00 Cr

PART PREPARATION/FIXTURING:

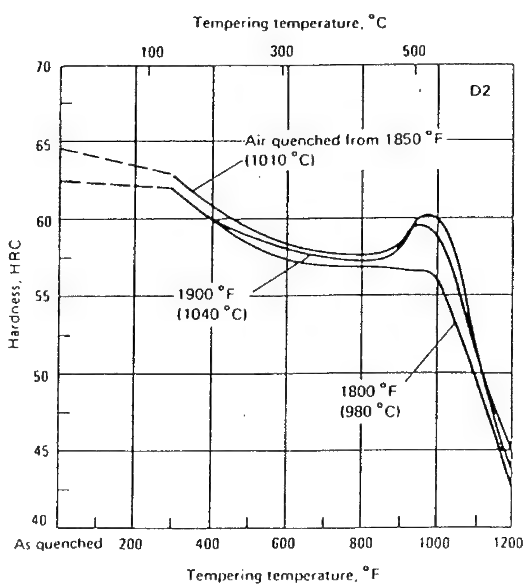
PROCESS PARAMETERS:

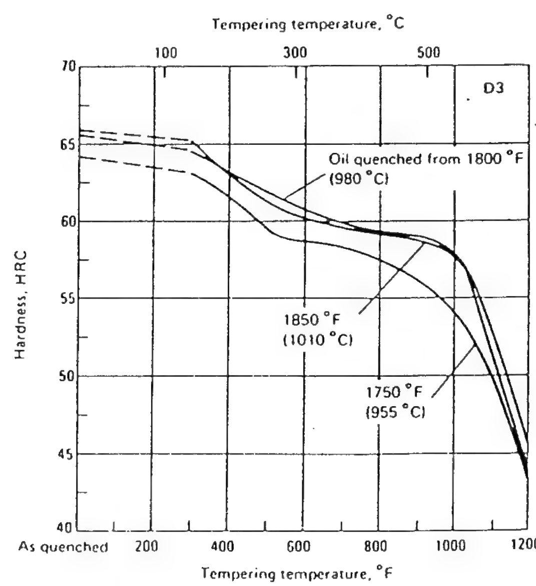
PROCESS:	Neutral Hardening
1ST PREHEAT:	1500°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1700 to 1800°F (15 to 45 minutes, depending on cross section) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Warm Oil or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 64 to 66 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper



D3: Hardness Versus Tempering Temperature. Austinitized at 1800 °F (980 °C) and 1750 °F (955 °C), quenched in oil. (Source: Universal-Cyclops)

D3: Comparison of Tempering Characteristics. D2 and D3 tool steels quenched from several austenitizing temperatures. Steels were austenitized in an air furnace. A recirculating pit-type furnace was used for tempering. Curves represent steel from three suppliers; an average of five hardness measurements made on each specimen from each supplier. Specimens were 1 in. in diameter and 1½ in. long. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)





Appendix A

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **D4**
High Carbon, High Chromium Cold Work Tool Steel (D Series)
CHEMICAL COMPOSITION: AISI Nominal. 2.25 C, 1.00 Mo, 12.00 Cr

PART PREPARATION/FIXTURING

PROCESS PARAMETERS

PROCESS: Neutral Hardening

1ST PREHEAT: 1500°F

2ND PREHEAT: N/A

AUSTENITIZE: 1775 TO 1850°F (15 TO 45 minutes, depending on cross section). Note: time at temp.

QUENCH: Fluidized Bed Quench Bath Operating on Nitrogen

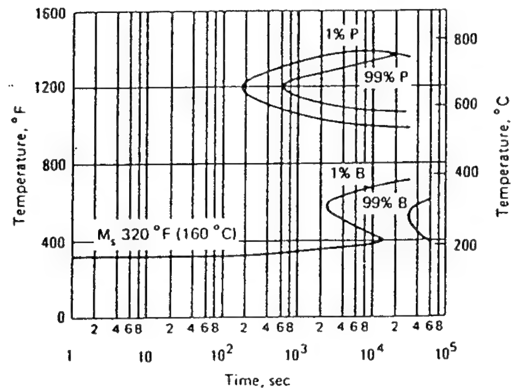
1ST TEMPER: See " Hardness vs. Tempering Temperature" Curve
1 to 2 hours at temperature

2ND TMEPER: Required (same as above)

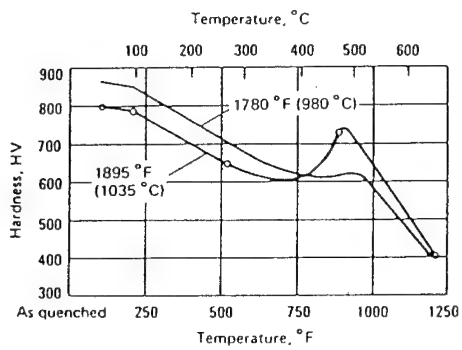
3RD TEMPER: N/A

COMMENTS:
- Approximate as quenched hardness: HRC 64 to 66
- Temper immediately after quench, when part has cooled to approximately 120 to 150°F
- Atmosphere for Preheat & Austenitize: 100% Nitrogen
- Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.
- Cool to room temperature after each temper.

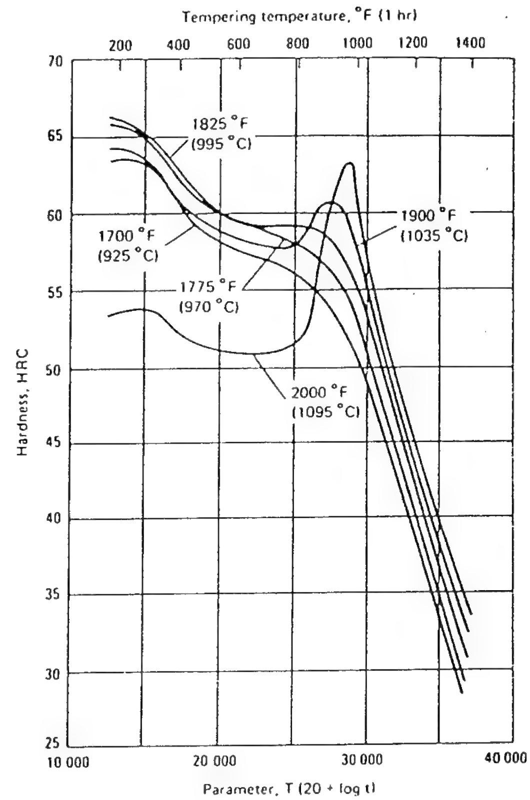
D4: Isothermal Transformation Diagram. Austenitized at 1800 °F (980 °C). (Source: *Tool Steels*, American Society for Metals, 1980)



D4: Hardness Versus Tempering Temperature. Austenitized at 1780 °F (970 °C) and 1895 °F (1035 °C), and cooled in air. (Source: *Tool Steels*, American Society for Metals, 1980)



D4: Hardness Versus Tempering Temperature. Tempering curves for D4 tool steel containing 2.17 C, 11.68 Cr, 0.78 V, 0.51 Co; austenitized at the five temperatures shown, cooled in air, and tempered for 1 hr at the tempering temperature. (Source: Teledyne VASCO)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

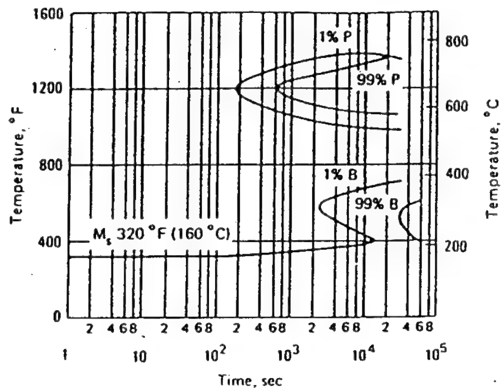
TYPE OF STEEL: **D5**
High Carbon, High Chromium Cold Work Tool Steel (D Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.50 C, 1.00 Mo, 12.00 Cr, 3.00 Co

PART PREPARATION/FIXTURING:

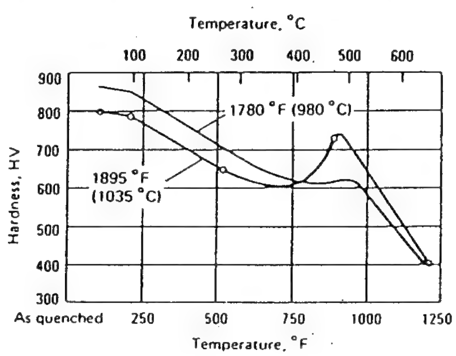
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1500°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1800 to 1875°F (15 to 45 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 61 to 64 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Tempering parameters for D4 are applicable, (approx.) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

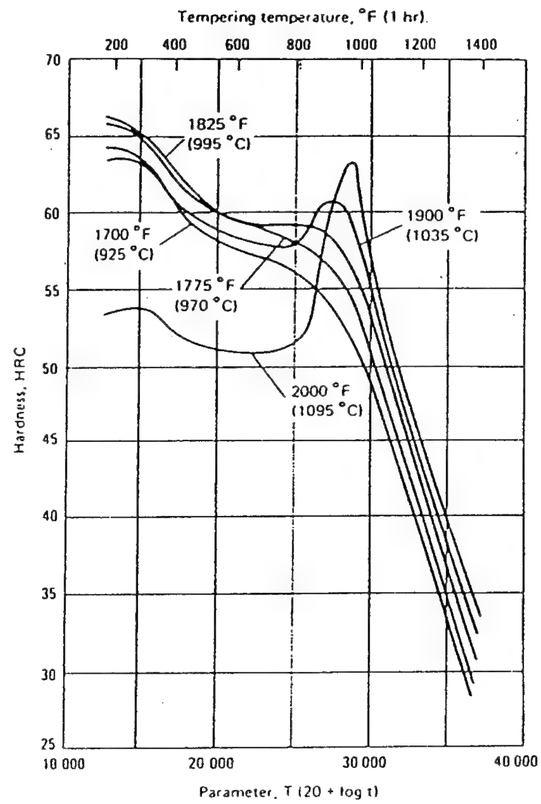
D4: Isothermal Transformation Diagram. Austenitized at 1800 °F (980 °C). (Source: *Tool Steels*, American Society for Metals, 1980)



D4: Hardness Versus Tempering Temperature. Austenitized at 1780 °F (970 °C) and 1895 °F (1035 °C), and cooled in air. (Source: *Tool Steels*, American Society for Metals, 1980)



D4: Hardness Versus Tempering Temperature. Tempering curves for D4 tool steel containing 2.17 C, 11.68 Cr, 0.78 V, 0.51 Co; austenitized at the five temperatures shown, cooled in air, and tempered for 1 hr at the tempering temperature. (Source: Teledyne VASCO)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

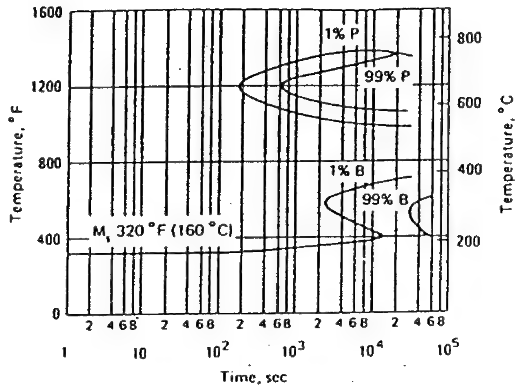
TYPE OF STEEL: D7
High Carbon, High Chromium Cold Work Tool Steel (D Series)
CHEMICAL COMPOSITION: AISI: Nominal. 2.35 C, 1.00 Mo, 12.00 Cr, 4.00 V

PART PREPARATION/FIXTURING:

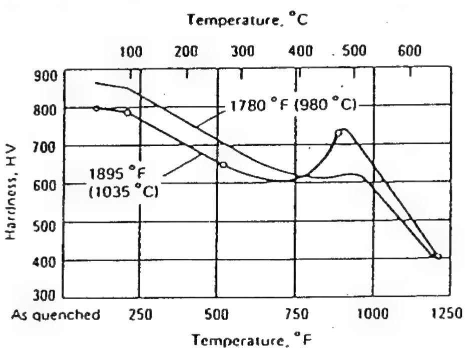
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1500°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1850 to 1950°F (30 to 60 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	Required (same as above)
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 63 to 66 - Temper immediately, after quench, when part has cooled to approx. 120 to 150°F - Tempering parameters for D4 are applicable, (approx.) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Cool to room temp. after each temper

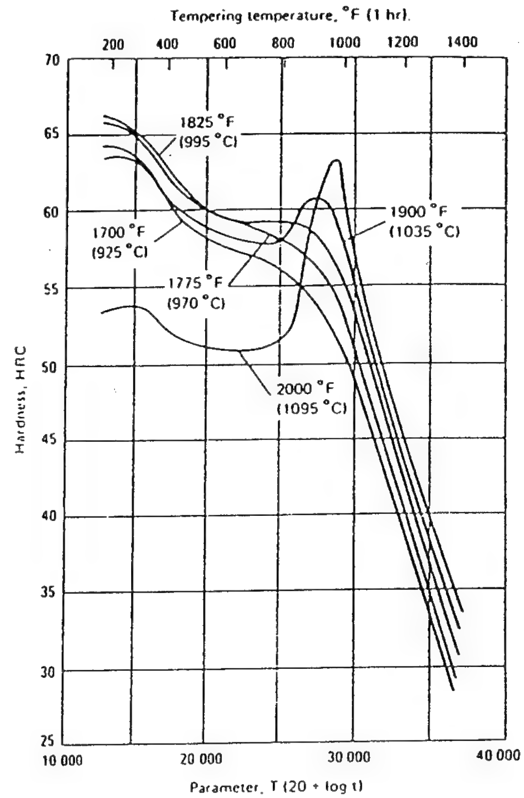
D4: Isothermal Transformation Diagram. Austenitized at 1800 °F (980 °C). (Source: *Tool Steels*, American Society for Metals, 1980)



D4: Hardness Versus Tempering Temperature. Austenitized at 1780 °F (970 °C) and 1895 °F (1035 °C), and cooled in air. (Source: *Tool Steels*, American Society for Metals, 1980)



D4: Hardness Versus Tempering Temperature. Tempering curves for D4 tool steel containing 2.17 C, 11.68 Cr, 0.78 V, 0.51 Co; austenitized at the five temperatures shown, cooled in air, and tempered for 1 hr at the tempering temperature. (Source: Teledyne VASCO)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

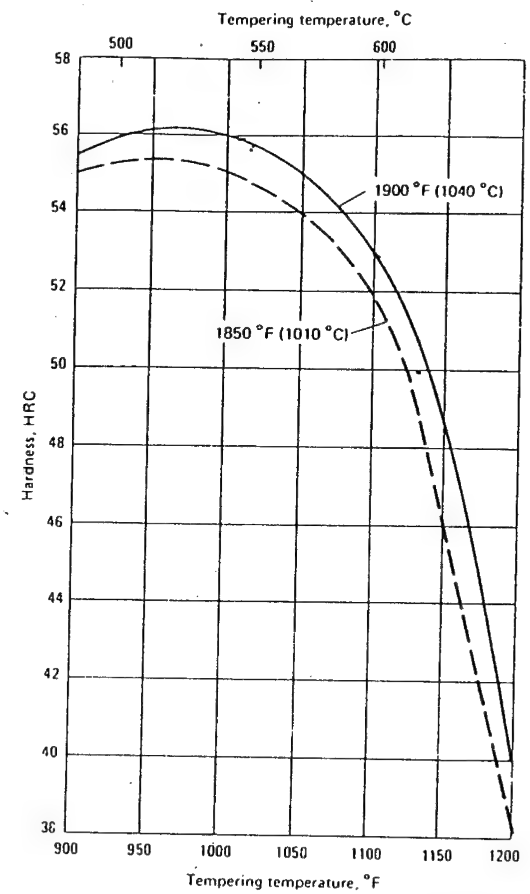
HEAT TREAT DATA SHEET

TYPE OF STEEL: H10
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.40 C, 2.50 Mo, 3.25 Cr, 0.40 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	1850 to 1900°F (15 to 40 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 52 to 59 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper



H10: Hardness Versus Tempering Temperature. H10, air cooled from 1900 °F (1040 °C) and 1850 °F (1010 °C). Double tempered. (Source: Universal-Cyclops)

H11

Chemical Composition. **AISI:** Nominal. 0.35 C, 1.50 Mo, 5.00 Cr, 0.40 V. **UNS:** 0.33 to 0.43 C, 4.75 to 5.50 Cr, 0.20 to 0.50 Mn, 1.10 to 1.60 Mo, 0.030 P max, 0.030 S max, 0.80 to 1.20 Si, 0.30 to 0.60 V

Similar Steels (U.S. and/or Foreign). UNS T20811; AMS 6437, 6485, 6487, 6488; ASTM A681 (H-11); FED QQ-T-570 (H-11); SAE J437 (H11), J438 (H11), J467 (H11); (U.K.) BS BH11; (W. Ger.) DIN 1.2343; (Fr.) AFNOR Z38 CDV5; (Ital.) UNI X 35 CrMo 05 KU; (Jap.) JIS SKD 6

Characteristics. A popular and relatively economical grade of hot work steel suitable for many applications. Is deep hardening, has excellent resistance to heat checking, and can be water cooled in service. Can be carburized or nitrided with some loss in resistance to heat checking. Has high resistance to softening at elevated temperature. Hardness does not vary up to 800 °F (425 °C), and tools can withstand working temperature up to 1100 °F (595 °C). Does not exhibit notable secondary hardening effect during tempering because of low carbon content. Hardness begins to drop off rapidly when tempering above 1050 °F (565 °C). Has high toughness, very low distortion in heat treating, and medium wear resistance. Has medium-to-high machinability and medium resistance to decarburization

Forging. Heat slowly. Preheat at 1300 to 1500 °F (705 to 815 °C), start forging at 1950 to 2100 °F (1065 to 1150 °C), and do not forge below 1650 °F (900 °C). Cool slowly

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Surface protection against decarburization by use of pack, controlled atmosphere, or vacuum is required. Heat to 1550 to 1650 °F (845 to 900 °C). Use lower limit for small sections and upper limit for large sections. Heat slowly and uniformly especially for hardened tools. Holding time varies from about 1 hr for light sections and small furnace charges to about 4 hr for heavy sections and large charges. For pack annealing, hold 1 hr per inch of cross section. Cool slowly in furnace at a rate not exceeding 50 °F (28 °C) per hour until 1000 °F (540 °C) is reached, after which a faster cooling rate will not affect final hardness. Typical annealed hardness, 192 to 235 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Surface protection against decarburization or carburization is required by utilizing salt, pack, controlled

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

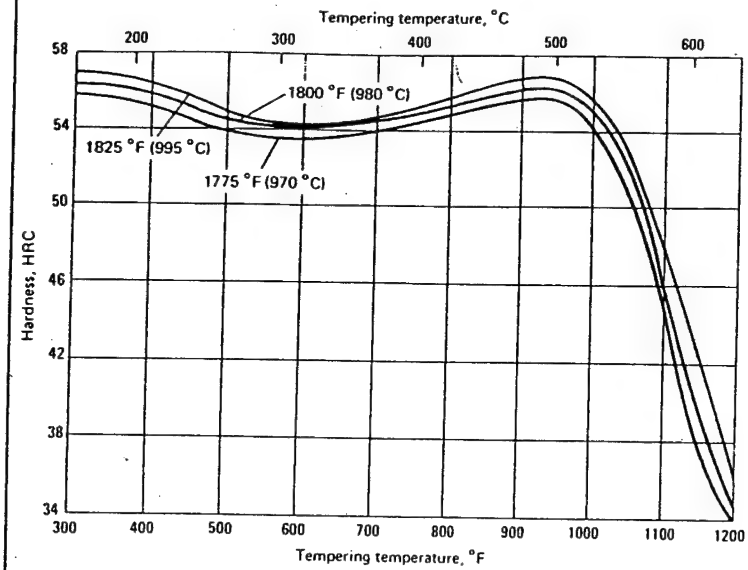
HEAT TREAT DATA SHEET

TYPE OF STEEL: H11
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.35 C, 1.50 Mo, 5.00 Cr, 0.40 V

PART PREPARATION/FIXTURING:

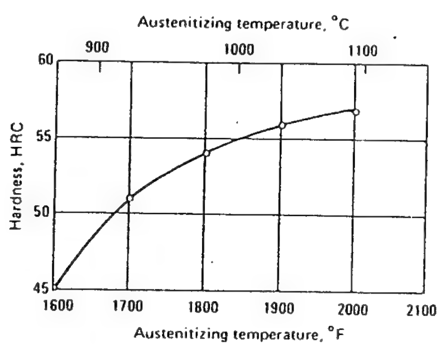
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	1825 to 1875°F (15 to 40 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 53 to 55 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

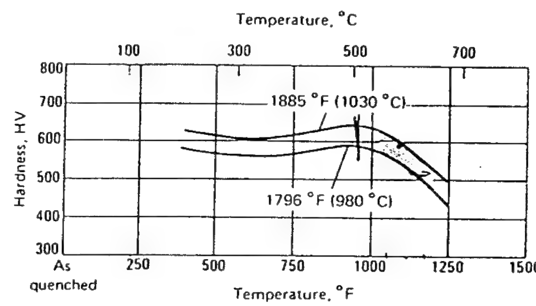


H11: As-Quenched Hardness Versus Austenitizing Temperature. H11 tool steel: 0.38 C, 1.00 Si, 5.25 Cr, 1.35 Mo, 0.50 V. Test specimens: 1 in. diam, 3 in. long. Cooled in air. (Source: Columbia Tool Steel and Latrobe Steel)

H11: Hardness Versus Austenitizing and Tempering Temperatures. H11 air cooled from 1825 °F (995 °C), 1800 °F (980 °C), 1775 °F (970 °C). (Source: Universal-Cyclops)



H11: Hardness Versus Austenitizing and Tempering Temperatures. English grade of H11 tool steel. (Source: British Steel)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: H12
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.35 C 1.50 W 1.50 Mo, 5.00 Cr, 0.40 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	1825 to 1875°F (15 to 40 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 53 to 55 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

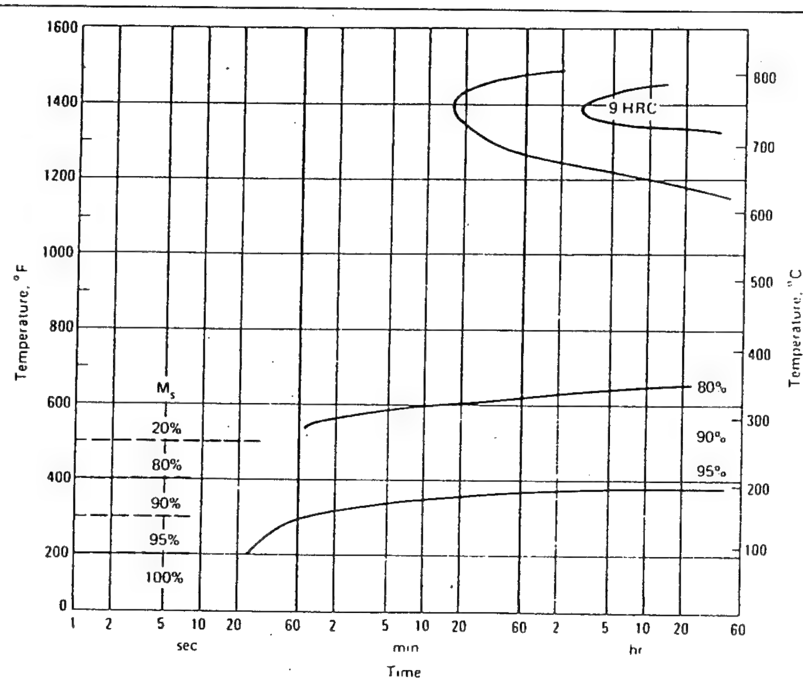
temperature into a salt bath held at 1100 to 1200 °F (595 to 650 °C), holding in the quench until the workpiece reaches the temperature of the bath, and then withdrawing the workpiece and allowing it to cool in air. Quenched hardness, 53 to 55 HRC

Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) briefly. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

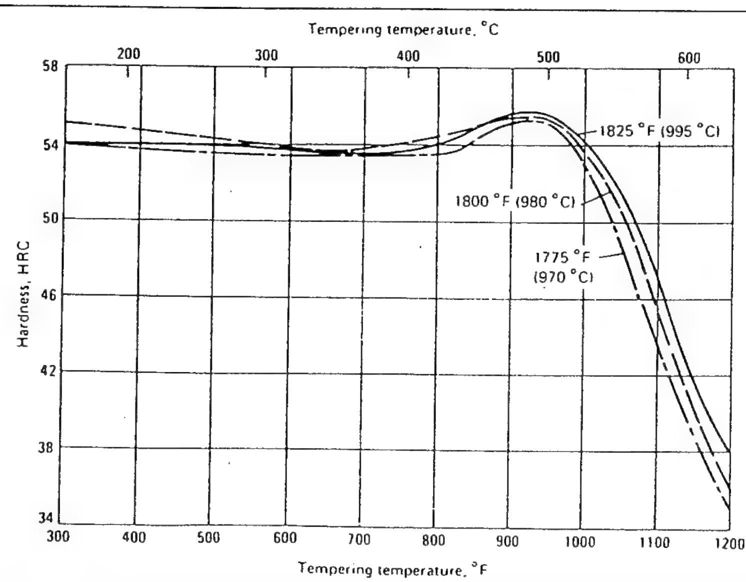
Tempering. Temper immediately after tool reaches about 125 °F (52 °C) at 1000 to 1200 °F (540 to 650 °C). Forced convection air tempering furnaces heat tools at a moderately safe rate. Salt baths are acceptable for small parts but may cause cracking of large or intricate shaped dies due to thermal shock. Temper for 1 hr per inch of thickness, cool to room temperature, and retemper using the same time at temperature. Second temper is essential and a third temper would be beneficial. Approximate tempered hardness, 55 to 38 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size



H12: Isothermal Transformation Diagram. Annealed H12 tool steel: 0.32 C, 0.35 Mn, 0.95 Si, 4.86 Cr, 1.45 Mo, 1.29 W. Austenitizing temperature 1850 °F (1010 °C). Critical (Ac_1) 1535 °F (835 °C). (Source: *Tool Steels*, American Society for Metals, 1980)



H12: Hardness Versus Austenitizing and Tempering Temperatures. H12 air cooled from 1825 °F (995 °C), 1800 °F (980 °C), 1775 °F (970 °C), and tempered. (Source: Universal-Cyclops)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

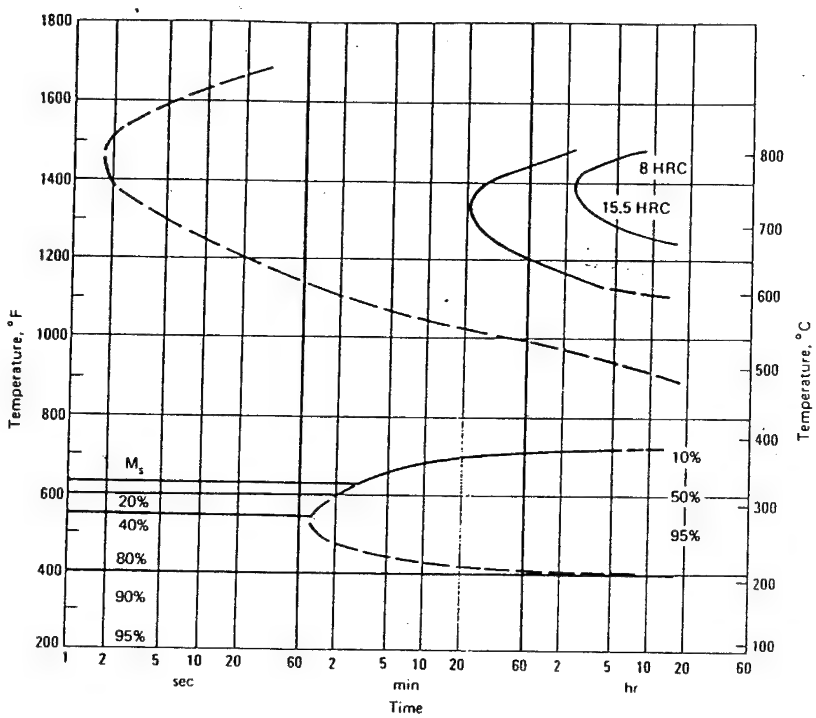
HEAT TREAT DATA SHEET

TYPE OF STEEL: H13
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.35 C 1.50 Mo, 5.00 Cr, 1.00 V

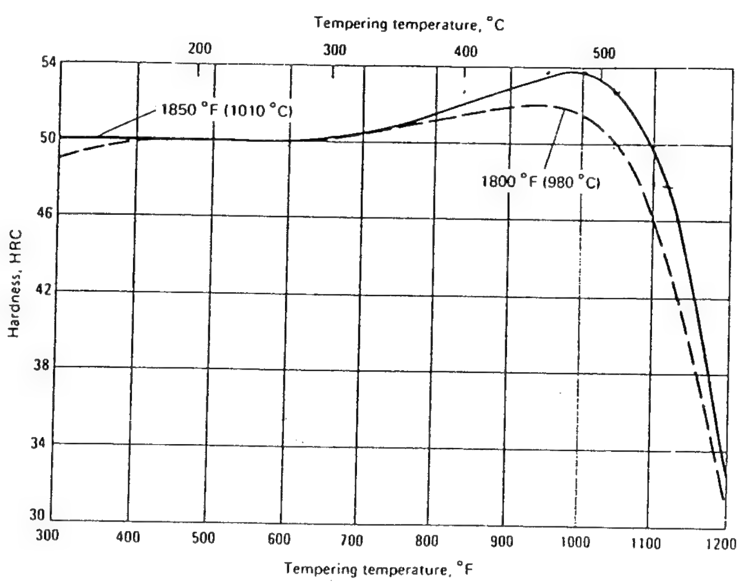
PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	1825 to 1900°F (15 to 40 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 51 to 54 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper



H13: Isothermal Transformation Diagram. Diagram for H13 tool steel, containing 0.40 C, 1.05 Si, 5.00 Cr, 1.35 Mo, 1.10 V. Austenitized at 1850 °F (1010 °C). (Source: Crucible Steel)



H13: Hardness Versus Tempering Temperature. H13, air cooled from 1850 °F (1010 °C) and 1800 °F (980 °C) and double tempered. (Source: Universal-Cyclops)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

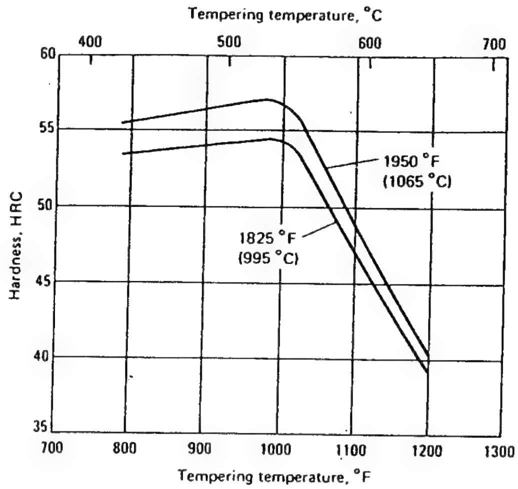
TYPE OF STEEL: H14
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal: 0.40 C, 5.00 W, 5.00 Cr

PART PREPARATION/FIXTURING:

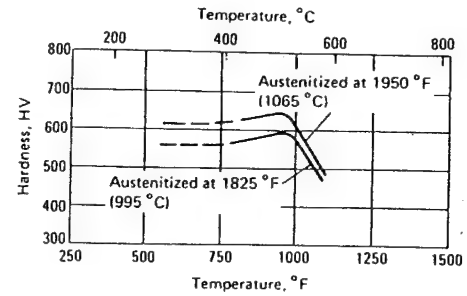
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	1850 to 1950°F (15 to 40 minutes, depending on cross section) note: time at temp.
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 53 to 57 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

H14: Hardness Versus Tempering Temperature. H14 austenitized at the temperatures shown, air quenched, receiving single temper for 4 hr. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



H14: Hardness Versus Tempering Temperature. H14 austenitized at the temperatures shown. (Source: *Tool Steels*, American Society for Metals, 1980)



H19

Chemical Composition. AISI: Nominal. 0.40 C, 4.25 W, 4.25 Cr, 2.00 V, 4.25 Co. **UNS:** 0.32 to 0.45 C, 4.00 to 4.50 Co, 4.00 to 4.50 Cr, 0.20 to 0.50 Mn, 0.30 to 0.55 Mo, 0.030 P max, 0.030 S max, 0.20 to 0.50 Si, 1.75 to 2.20 V, 3.75 to 4.50 W

Similar Steels (U.S. and/or Foreign). UNS T20819; ASTM A681 (H-19); FED QQ-T-570 (H-19)

Characteristics. A chromium-tungsten grade with 2% vanadium and 4.25% cobalt added. Requires high austenitizing temperature and short time at heat. Can be air cooled or oil quenched from hardening temperature. Exhibits greater secondary hardness than any of the H steels with identification numbers less than H19 (H14, H13 etc.). Hardness begins to drop off rapidly when tempering above 1025 °F (550 °C). Has high toughness and resistance to softening at elevated temperature. Has medium to high wear resistance, medium machinability, and resistance to decarburization

Forging. Heat slowly. Preheat at 1300 to 1500 °F (705 to 815 °C), start forging at 1900 to 2100 °F (1040 to 1150 °C), and do not forge below 1650 °F (900 °C). Cool slowly

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat to 1600 to 1650 °F (870 to 900 °C). Use lower limit for small sections and upper limit for large sections. Surface protection against decarburization by use of pack, controlled atmosphere, or vacuum is required. Heat slowly and uniformly especially for hardened tools. Holding time varies from about 1 hr for light sections and small furnace charges to about 4 hr for heavy sections and large charges. For pack annealing, hold 1 hr per inch of cross section. Cool slowly in furnace at a rate not exceeding 50 °F (28 °C) until 1100 °F (595 °C) is reached, when a faster cooling rate will not affect final hardness. Typical annealed hardness, 207 to 241 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Surface protection against decarburization or carburization is required by utilizing salt, pack, controlled atmosphere, or vacuum. For preheating, die blocks or other tools for open furnace treatment should be placed in a furnace that is not over 500 °F (260 °C). Work that is packed in containers may be placed safely in furnace at 700 to 1000 °F (370 to 535 °C). Once the workpiece (or container) has reached temperature, heat slowly (not faster than 200 °F or 110 °C per hour) to 1500 °F (815 °C). Hold for one hr per inch of thickness (or per inch of container thickness if packed). If double preheating facilities, such as salt baths, are available, thermal shock can be reduced by preheating at 1000 to 1200 °F (540 to 650 °C) and further preheating at 1550 to 1600 °F (845 to 870 °C). Heat rapidly to austenitizing temperature of 2000 to 2200 °F (1095 to 1205 °C) and hold for 2 to 5 min. Do not over soak. When using salt baths, reduce temperature by 25 °F (14 °C). Use shorter time for small sections and longer time for large sections. Quench in air. If blast cooling, air should be dry and blasted uniformly on surface to be hardened. To minimize scale, tools can be flash quenched in oil to cool the surface below scaling temperature (about 1000 °F or 540 °C), but this increases distortion. The procedure is best carried out by quenching from the austenitizing temperature in a salt bath held at 1100 to 1200 °F (595 to 650 °C), holding in the quench until the workpiece reaches the temperature of the bath, and withdrawing the workpiece and allowing it to cool in air. Quench hardness, 48 to 57 HRC

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: H19
Hot Work Tool Steel (H Series)

CHEMICAL COMPOSITION: AISI: Nominal: 0.40 C, 4.25 W, 4.25 Cr, 2.00 V, 4.25 Co

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

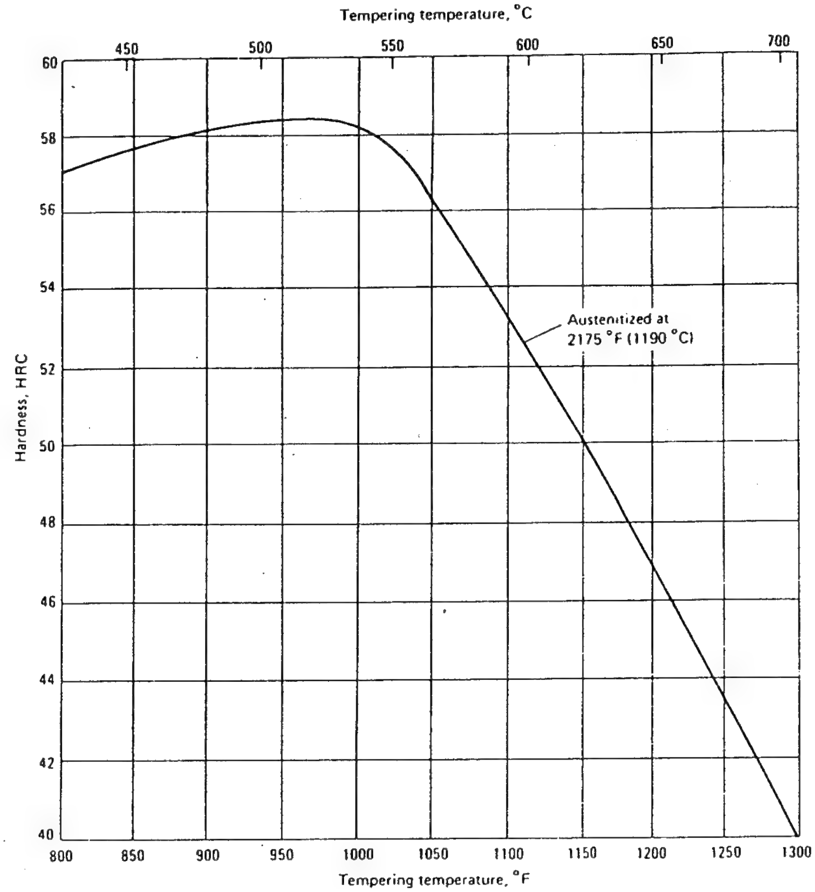
PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2000 to 2200°F (2 to 5 minutes, depending on cross section) note: time at temp. Do not over soak
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 48 to 57 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) briefly. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

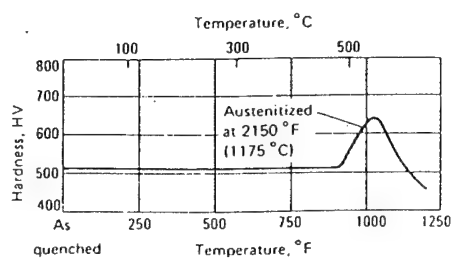
Tempering. Temper immediately after tool reaches about 125 °F (52 °C) at 1000 to 1300 °F (540 to 705 °C). Forced convection air tempering furnaces heat tools at a moderately safe rate. Salt baths are acceptable for small parts but may cause cracking of large or intricate shaped dies because of thermal shock. Temper for 1 hr per inch of thickness, cool to room temperature, and retemper using the same time at temperature. The second temper is essential and a third temper would be beneficial. Approximate tempered hardness, 57 to 40 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size



H19: Hardness Versus Tempering Temperature. H19 oil quenched from 2175 °F (1190 °C) and double tempered. (Source: Universal-Cyclops)



H19: Hardness Versus Tempering Temperature. H19 austenitized at 2150 °F (1175 °C). (Source: Jessop-Saville)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

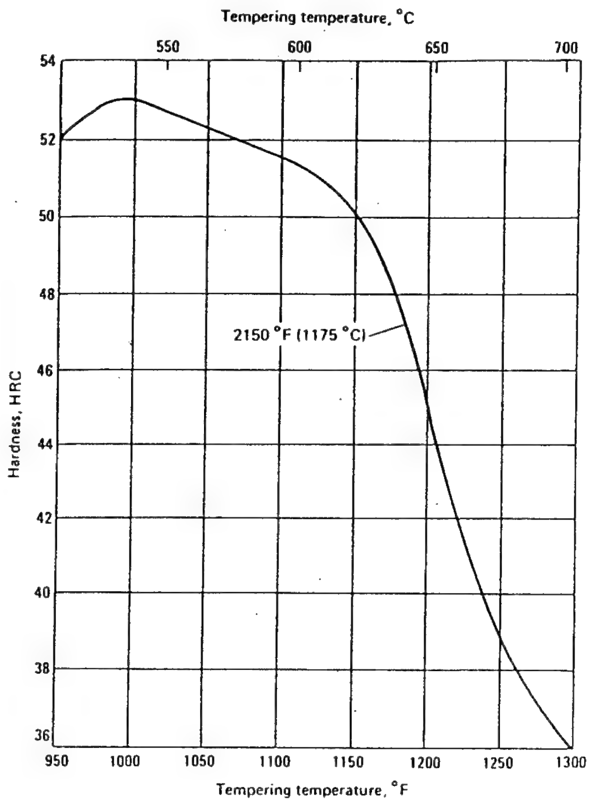
TYPE OF STEEL: **H21**
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.35 C, 9.00 W, 3.50 Cr, 0.50 V

PART PREPARATION/FIXTURING:

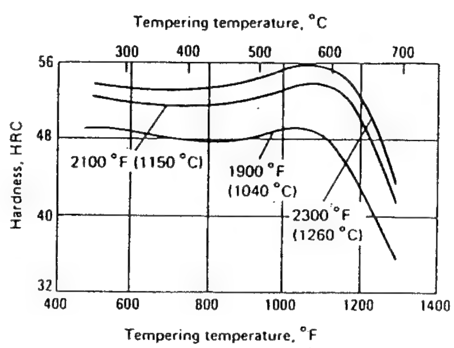
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2000 to 2200°F (2 to 5 minutes, depending on cross section) note: time at temp. Do not over soak
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 45 to 53 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

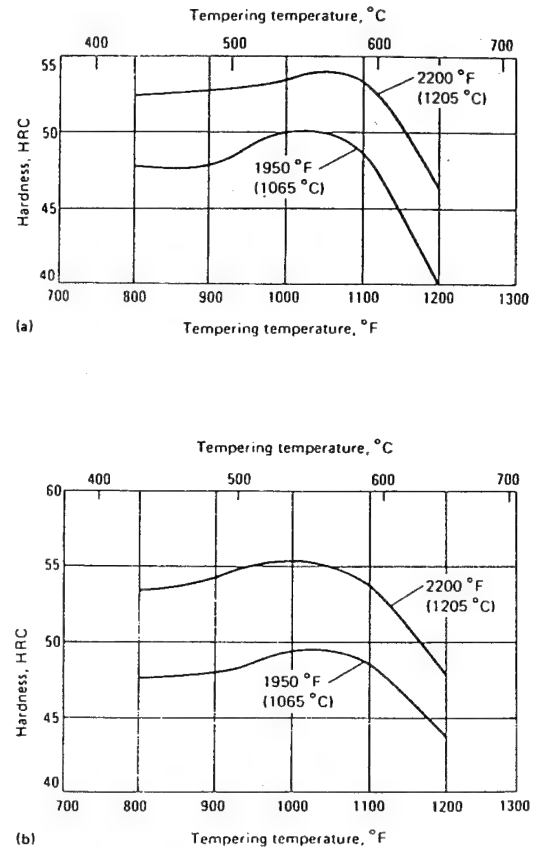
H21: Hardness Versus Tempering Temperature. H21 oil quenched at 2150 °F (1175 °C) and double tempered. (Source: Universal-Cyclops)



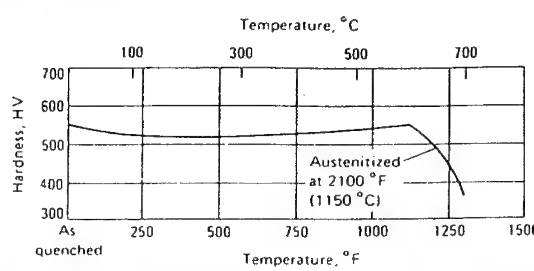
H21: Hardness Versus Tempering Temperature. H21 oil quenched from the indicated temperatures. (Source: Teledyne VASCO)



H21: Hardness Versus Tempering Temperature. (a) H21 austenitized at the temperatures shown, oil quenched, receiving single temper for 2 hr. (b) H21, austenitized at the temperature shown, air quenched, receiving single temper for 2 hr. (Source: *Metals Handbook,* 8th ed., Vol 2, American Society for Metals, 1964)



H21: Hardness Versus Tempering Temperature. H21 austenitized at the temperature shown. (Source: Jessop-Saville)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

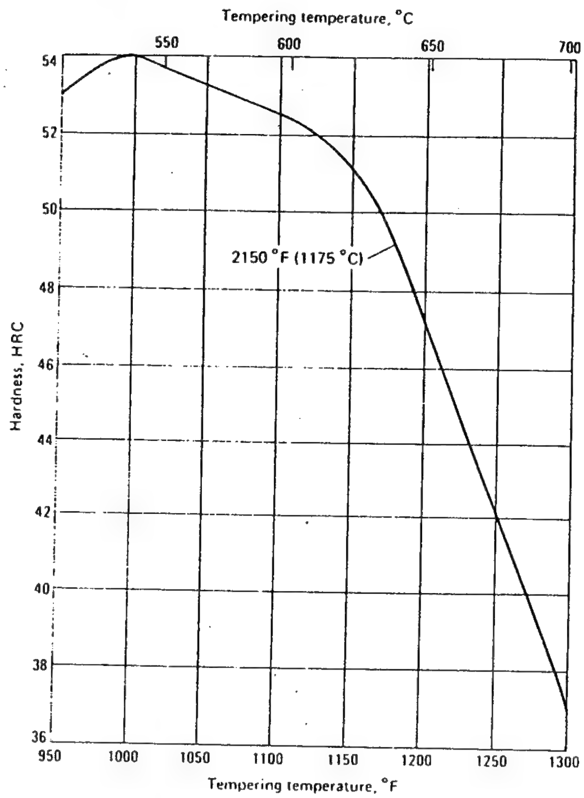
TYPE OF STEEL: **H22**
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.35 C, 11.00 W, 2.00 Cr, 0.40 V

PART PREPARATION/FIXTURING:

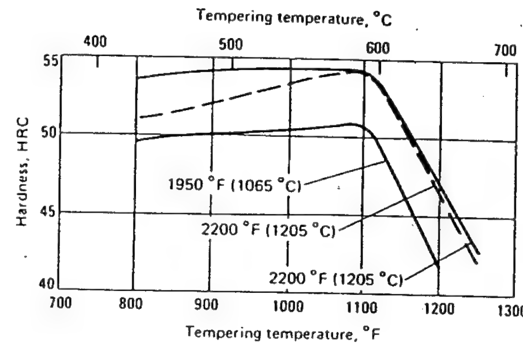
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2000 to 2200°F (2 to 5 minutes, depending on cross section) note: time at temp. Do not over soak
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 48 to 56 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

H22: Hardness Versus Tempering Temperature. H22 oil quenched from 2150 °F (1175 °C) and double tempered. (Source: Universal-Cyclops)



H22: Hardness Versus Tempering Temperature. H22 austenitized at 1950 °F (1065 °C) and oil quenched, austenitized at 2200 °F (1205 °C) and air quenched, and austenitized at 2200 °F (1205 °C) and oil quenched. Each received single temper for 2 hr. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



H23

Chemical Composition. **AISI:** Nominal. 0.30 C, 12.00 W, 12.00 Cr, 1.00 V. **UNS:** 0.25 to 0.35 C, 11.00 to 12.75 Cr, 0.15 to 0.40 Mn, 0.030 P max, 0.030 S max, 0.15 to 0.60 Si, 0.75 to 1.25 V (optional), 11.00 to 12.75 W

Similar Steels (U.S. and/or Foreign). UNS T20823; ASTM A681 (H-23); FED QQ-T-570 (H-23); (W. Ger.) DIN 1.2625

Characteristics. A relatively low carbon grade containing 12% tungsten and 12% chromium. Has very high resistance to softening at elevated temperature and high resistance to hardness drop during tempering. Is deep hardening and exhibits unusually high secondary hardening during tempering. Requires high austenitizing temperature and short time at heat. At an austenitizing temperature of 2300 °F (1260 °C), has duplex structure of austenite and ferrite. On isothermal transformation, precipitation from the ferrite (of iron tungsten) begins within a few seconds which is not detrimental to as quenched or final hardness. More important, the nose of the transformation curve is encountered in only 60 sec at 1800 °F (980 °C). Therefore, oil quenching or a strongly agitated hot salt bath (preferably cascade type) at about 350 °F (175 °C) is used. The Ms temperature is approximately −50 °F (−45 °C). As quenched structure consists of undissolved carbide, austenite, and ferrite. (Absence of martensite explains resistance to tempering.) As quenched hardness, 34 to 40 HRC. During tempering, it will increase to the usual working hardness of 34 to 48 HRC. Hardness begins to drop off gradually at 1000 to 1100 °F (540 to 595 °C) and very rapidly in the 1200 to 1300 °F (650 to 705 °C) range. Has medium toughness, medium to high wear resistance, and medium machinability and resistance to decarburization

Forging. Heat slowly. Preheat at 1450 to 1550 °F (790 to 845 °C), start forging at 1950 to 2150 °F (1065 to 1175 °C), and do not forge below 1800 °F (980 °C). Cool slowly

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat to 1600 to 1650 °F (870 to 900 °C). Use lower limit for small sections and upper limit for large sections. Surface protection against decarburization by use of pack, controlled atmosphere, or vacuum is required. Heat slowly and uniformly especially for hardened tools. Holding time varies from about 1 hr for light sections and small furnace charges to about 4 hr for heavy sections and

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: H23
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.30 C, 12.00 W, 12.00 Cr, 1.00 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2200 to 2300°F (2 to 5 minutes, depending on cross section) *note: time at temp. Do not over soak* 2200°F is the highest temp. available using Procedyne Fluidized Bed Furnaces.
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness.
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 34 to 40 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

large charges. For pack annealing, hold 1 hr per inch of cross section. Cool slowly in furnace at a rate not exceeding 50 °F (28 °C) per hour until 1100 °F (595 °C) is reached, when a faster cooling rate will not affect final hardness. Typical annealed hardness, 212 to 255 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Surface protection against decarburization or carburization is required by utilizing salt, pack, controlled atmosphere, or vacuum. For preheating, die blocks or other tools for open furnace treatment should be placed in a furnace that is not over 500 °F (260 °C). Work that is packed in containers may be safely placed in furnace at 700 to 1000 °F (370 to 540 °C). Once the workpiece (or container) has reached temperature, heat slowly (not faster than 200 °F or 110 °C per hour) to 1550 °F (845 °C). Hold for 1 hr per inch of thickness (or per inch of container thickness, if packed). If double preheating facilities, such as salt baths, are available, thermal shock can be reduced by preheating at 1000 to 1200 °F (540 to 650 °C) and further preheating at 1550 to 1600 °F (845 to 870 °C). Heat rapidly to austenitizing temperature of 2200 to 2300 °F (1205 to 1260 °C) and hold for 2 to 5 min. Do not over soak. When salt baths are used, reduce temperature by 25 °F (14 °C). Use shorter time for small sections and longer time for large sections. Quench from the austenitizing temperature in warm oil or an agitated salt bath held at 325 to 375 °F (165 to 190 °C), holding in the quench until workpiece reaches temperature of the bath, withdrawing workpiece, and allowing it to cool in air. Quenched hardness, 34 to 40 HRC

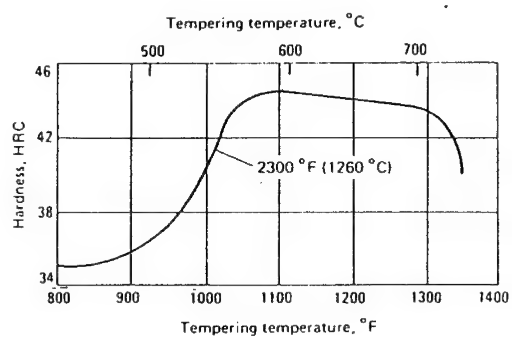
Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) briefly. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

Tempering. Temper immediately after tool reaches about 125 °F (52 °C) at 1200 to 1350 °F (650 to 730 °C). Forced convection air tempering furnaces heat tools at a moderately safe rate. Salt baths are acceptable for small parts but may cause cracking of large or intricate shaped dies because of thermal shock. Temper for 1 hr per inch of thickness, cool to room temperature, and retemper using the same time at temperature. The second temper is essential, and a third temper would be beneficial. Approximate tempered hardness, 48 to 34 HRC

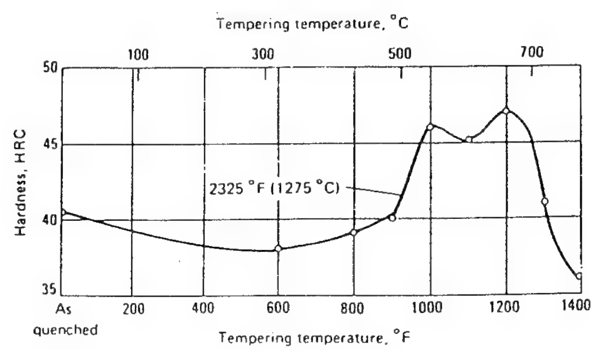
Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size

H23: Hardness Versus Tempering Temperature. H23 oil quenched from 2300 °F (1260 °C) and triple tempered (2 hr each). (Source: Universal-Cyclops)



H23: Hardness Versus Tempering Temperature. H23 containing 0.35 C, 0.33 Mn, 0.45 Si, 11.87 Cr, 12.07 W, 1.08 V. Austenitized at 2325 °F (1275 °C) and quenched in oil. (Source: Teledyne VASCO)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

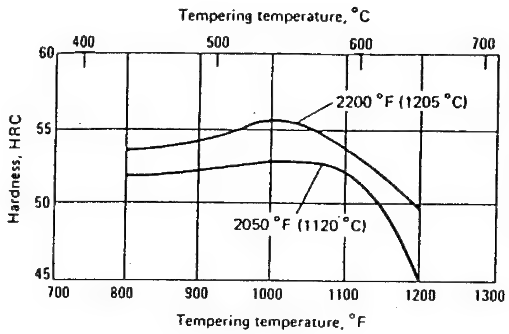
HEAT TREAT DATA SHEET

TYPE OF STEEL: H24
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal: 0.45 C, 15.00 W, 3.00 Cr, 0.50 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2000 to 2250°F (2 to 5 minutes, depending on cross section) note: time at temp. Do not over soak <u>2200°F is the highest temp. available using Procedyne Fluidized Bed Furnaces.</u>
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 52 to 56 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper



H24: Hardness Versus Tempering Temperature. H24 austenitized at the temperatures shown, oil quenched, and receiving single temper for 2 hr. (Source: *Metals Handbook,* 8th ed., Vol 2, American Society for Metals, 1964)

H25

Chemical Composition. **AISI:** Nominal. 0.25 C, 15.00 W, 4.00 Cr, 0.50 V. **UNS:** 0.22 to 0.32 C, 3.75 to 4.50 Cr, 0.15 to 0.40 Mn, 0.030 P max, 0.030 S max, 0.15 to 0.40 Si, 0.40 to 0.60 V (optional), 14.00 to 16.00 W

Similar Steels (U.S. and/or Foreign). UNS T20825; ASTM A681 (H-25); FED QQ-T-570 (H-25)

Characteristics. Very similar to H24, except has lower carbon content and 1% more chromium. A 15% tungsten hot work grade. Its relatively low level of carbon gives it a toughness rating equal to the popular 9% tungsten grades which have higher levels of carbon. The high tungsten imparts very high resistance to softening at elevated temperature. Requires high austenitizing temperature and short time at heat. Cannot be water cooled in service and should be ground with coarse open wheel. Hardness in tempering begins to drop after 1000 °F (540 °C) when the high end of the austenitizing range is used. Has high toughness, and medium wear resistance, machinability, and resistance to decarburization

Forging. Heat slowly. Preheat at 1450 to 1550 °F (790 to 845 °C), start forging at 1950 to 2150 °F (1065 to 1175 °C), and do not forge below 1700 °F (925 °C). Cool slowly

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat to 1600 to 1650 °F (870 to 900 °C). Use lower limit for small sections and upper limit for large sections. Surface protection against decarburization by use of pack, controlled atmosphere, or vacuum is required. Heat slowly and uniformly especially for hardened tools. Holding time varies from about 1 hr for light sections and small furnace charges to about 4 hr for heavy sections and large charges. For pack annealing, hold 1 hr per inch of cross section. Cool slowly in furnace at a rate not exceeding 50 °F (28 °C) per hour until 1100 °F (595 °C) is reached, when a faster cooling rate will not affect final hardness. Typical annealed hardness, 207 to 235 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Surface protection against decarburization or carburization is required by utilizing salt, pack, controlled atmosphere, or vacuum. For preheating, die blocks or other tools for open furnace treatment should be placed in a furnace that is not over 500 °F (260 °C). Work packed in containers may be safely placed in furnace at 700 to 1000 °F (370 to 540 °C). Once the workpiece (or container) has reached temperature, heat slowly (not faster than 200 °F or 110 °C per hour) to 1500 °F (815 °C). Hold for 1 hr per inch of thickness (or per inch of container thickness, if packed). If double preheating facilities, such as salt baths, are available, thermal shock can be reduced by preheating at 1000 to 1200 °F (540 to 650 °C) and further preheating at 1550 to 1600 °F (845 to 870 °C). Heat rapidly to austenitizing temperature of 2100 to 2300 °F (1150 to 1260 °C) and hold for 2 to 5 min. Do not over soak. When salt baths are used, reduce temperature by 25 °F (14 °C). Use shorter time for small sections and longer time for large sections. Quench in air. If blast cooling, air should be dry and blasted uniformly on surface to be hardened. To minimize scale, tools can be flash quenched in oil to cool the surface below scaling temperature (about 1000 °F or 540 °C), but this increases distortion. The procedure is best carried out by quenching from the austenitizing temperature in a salt bath held at 1000 to 1200 °F (595 to 650 °C), holding in the quench until the workpiece reaches the temperature of the bath, withdrawing the workpiece, and allowing it to cool in air. Quenched hardness, 33 to 46 HRC

Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) briefly. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **H25**
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.25 C, 15.00 W, 4.00 Cr, 0.50 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

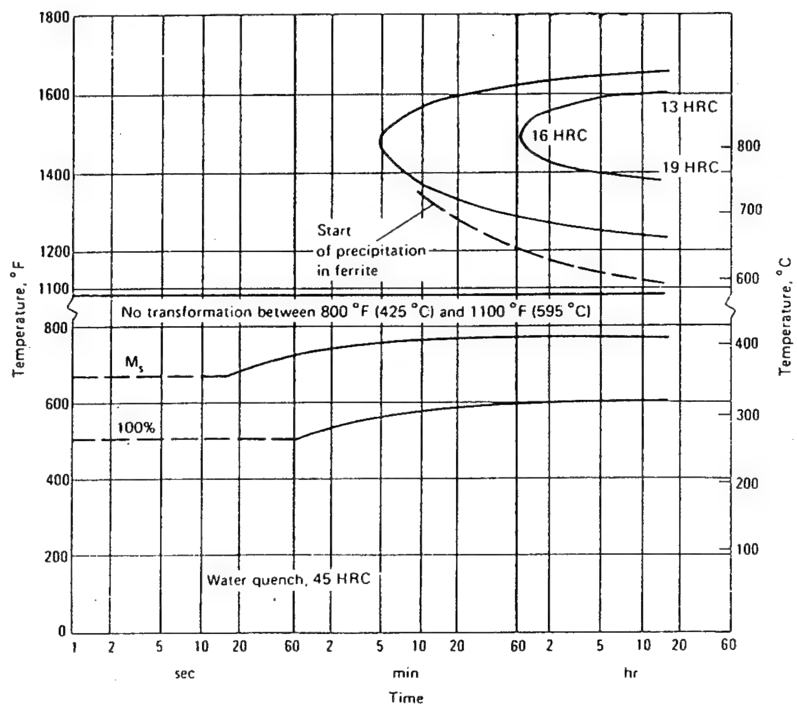
PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2100 to 2300°F (2 to 5 minutes, depending on cross section) note: time at temp. Do not over soak <u>2200°F is the highest temp. available using Procedyne Fluidized Bed Furnaces.</u>
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 33 to 46 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

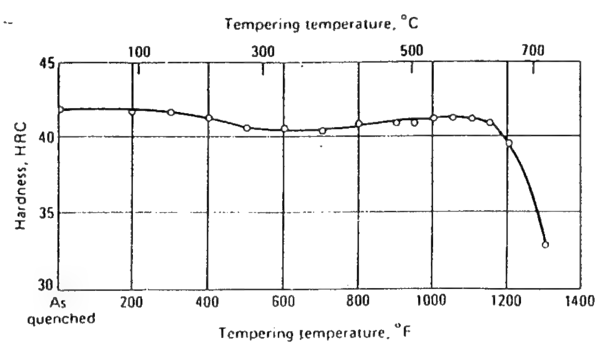
Tempering. Temper immediately after tool reaches about 125 °F (50 °C) at 1050 to 1250 °F (565 to 675 °C). Forced convection air tempering furnaces heat tools at a moderately safe rate. Salt baths are acceptable for small parts but may cause cracking of large or intricate shaped dies because of thermal shock. Temper for 1 hr per inch of thickness, cool to room temperature, and retemper using the same time at temperature. The second temper is essential, and a third temper would be beneficial. Approximate tempered hardness, 44 to 35 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size

H25: Isothermal Transformation Diagram. H25 containing 0.25 C, 4.00 Cr, 15.00 W, 0.50 V. Austenitized at 2150 °F (1175 °C). (Source: Crucible Steel)





H25: Hardness Versus Tempering Temperature. H25 containing 0.26 C, 14.30 W, 3.60 Cr, 0.40 V. Austenitized at 2150 °F (1175 °C) and quenched in oil. Specimen: 1/2-in. (13-mm) diam by 5/8 in. (15.8 mm). (Source: *Tool Steels*, American Society for Metals, 1980).

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

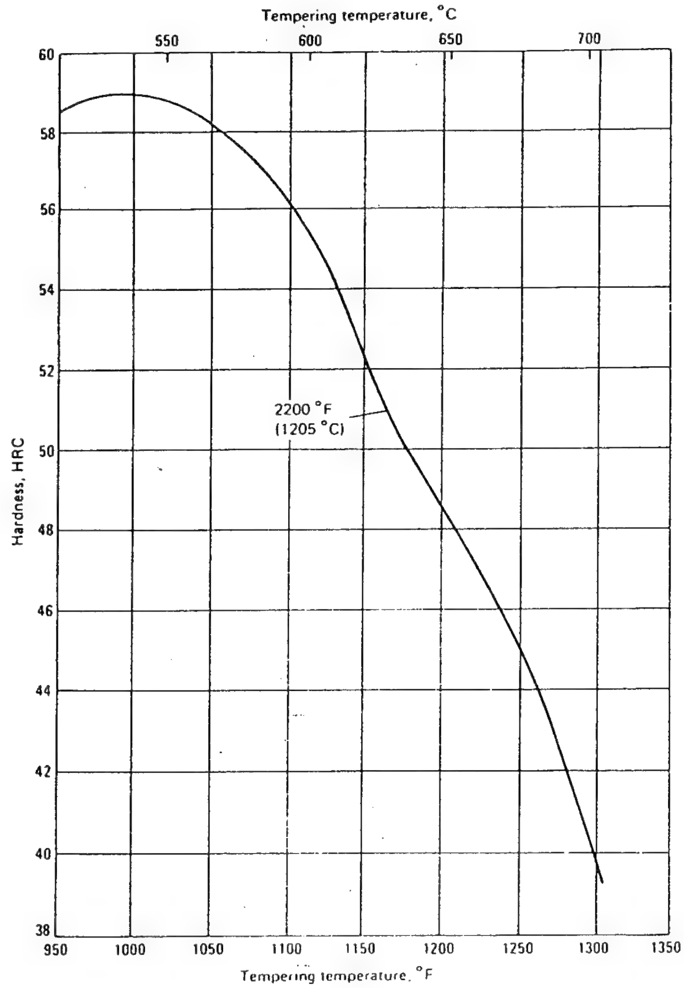
HEAT TREAT DATA SHEET

TYPE OF STEEL: H26
Hot Work Tool Steel (H Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.50 C, 18.00 W, 4.00 Cr, 1.00 V

PART PREPARATION/FIXTURING:

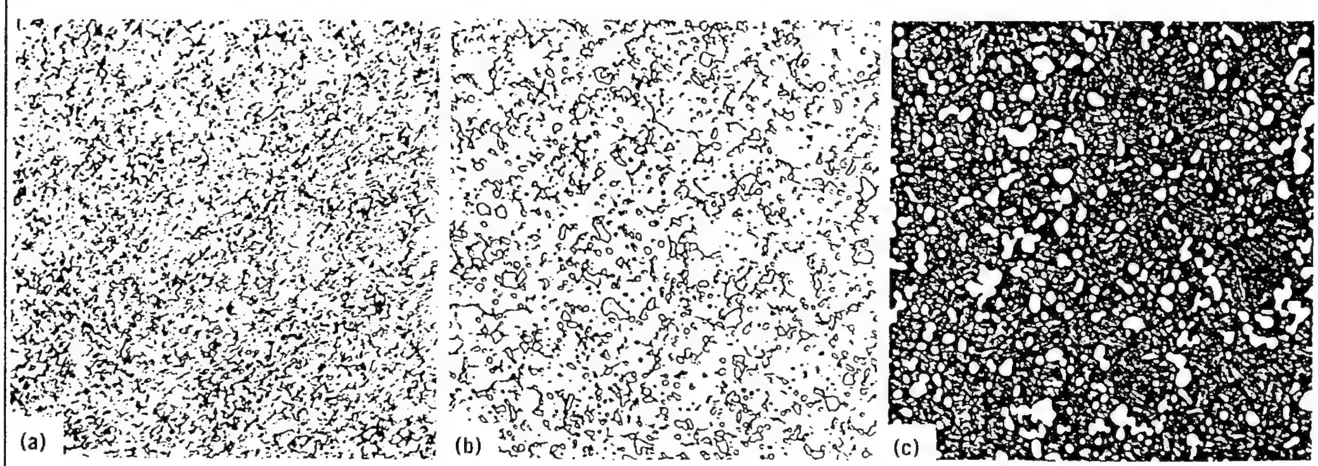
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2150 to 2300°F (2 to 5 minutes, depending on cross section) note: time at temp. Do not over soak <u>2200°F is the highest temp. available using Procedyne Fluidized Bed Furnaces.</u>
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 51 to 59 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper



H26: Hardness Versus Tempering Temperature. H26 oil quenched from 2200 °F (1205 °C) and double tempered. (Source: Universal-Cyclops)

H26: Microstructures



(a) Picral with HCl, for 10 sec, 500X. Annealed by austenitizing at 1650 °F (900 °C), cooling at 15 °F (8 °C) per hour to 1200 °F (650 °C), and air cooling. Hardness, 22 to 23 HRC. Dispersion of fine particles of alloy carbide in matrix of ferrite. (b) 4% nital, 500X. Austenitized at 2300 °F (1260 °C) and oil quenched. Hardness, 58 HRC. Small spheroidal carbide particles and some larger alloy carbide (principally tungsten carbide) in matrix of untempered martensite. (c) 4% nital, 500X. Austenitized at 2300 °F (1260 °C), oil quenched (2 hr plus 2 hr) at 1025 °F (550 °C). Hardness, 59 HRC. Particles of alloy carbide more clearly resolved in (b). Matrix tempered martensite. (Source: *Metals Handbook*, 8th ed., Vol 7, American Society for Metals, 1972)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **H42**
Hot Work Tool Steel (H Series)

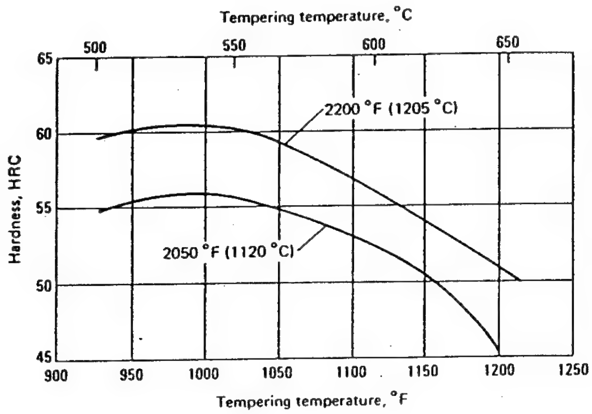
CHEMICAL COMPOSITION: AISI: Nominal. 0.60 C, 6.00 W, 5.00 Mo, 4.00 Cr, 2.00 V

PART PREPARATION/FIXTURING:

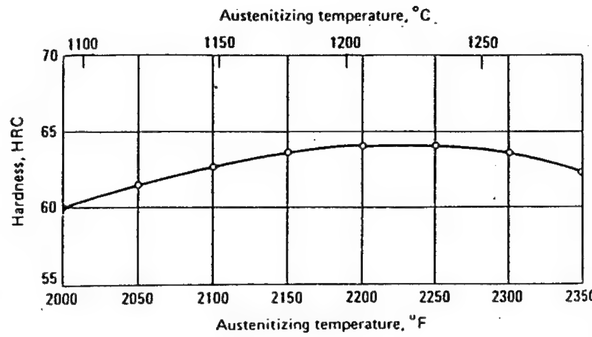
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	1550°F
AUSTENITIZE:	2050 to 2225°F (2 to 5 minutes, depending on cross section) note: time at temp. Do not over soak <u>2200°F is the highest temp. available using Procedyne Fluidized Bed Furnaces.</u>
STEP QUENCH:	1100°F, under 100% nitrogen, hold long enough to equalize part temperature (optional)
QUENCH:	Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour per inch of thickness
2ND TEMPER:	Required (same as above)
3RD TEMPER:	Optional
COMMENTS:	- Approx. As Quenched Hardness: HRC 54 to 62 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: 100% Nitrogen - Cool to room temp. after each temper

H42: Hardness Versus Tempering Temperature. H42 austenitized at 2200 °F (1205 °C) and 2050 °F (1120 °C) and oil quenched. (Source: *Metals Handbook,* 8th ed., Vol 2, American Society for Metals, 1964)



H42: Hardness Versus Austenitizing Temperature. H42 containing 0.68 C, 0.30 Si, 6.40 W, 5.00 Mo, 4.25 Cr, 1.90 V. Specimen oil quenched from indicated temperatures. (Source: Latrobe Steel and Bethlehem Steel)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

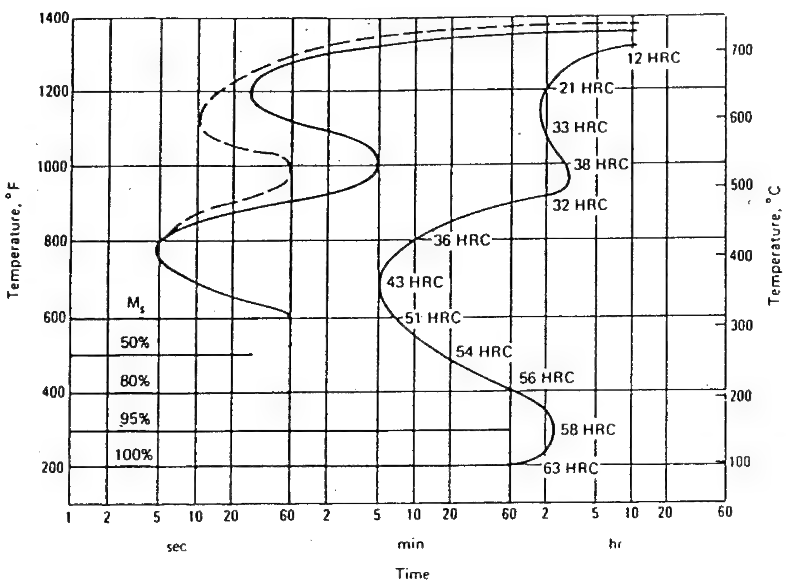
HEAT TREAT DATA SHEET

TYPE OF STEEL: **L2**
Low Alloy Special Purpose Tool Steel (L Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.50 to 1.10 C, 1.00 Cr, 0.20 V

PART PREPARATION/FIXTURING:

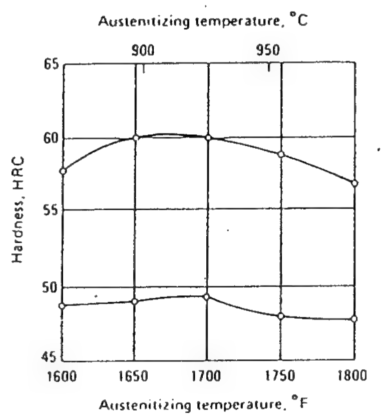
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1550 to 1700°F (10 to 30 minutes) if oil quenching 1450 to 1550°F (10 to 30 minutes) if water quenching note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Warm, agitated oil or polmer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 54 to 61 - Temper immediately, after quench, when part has cooled to approx. 125°F - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

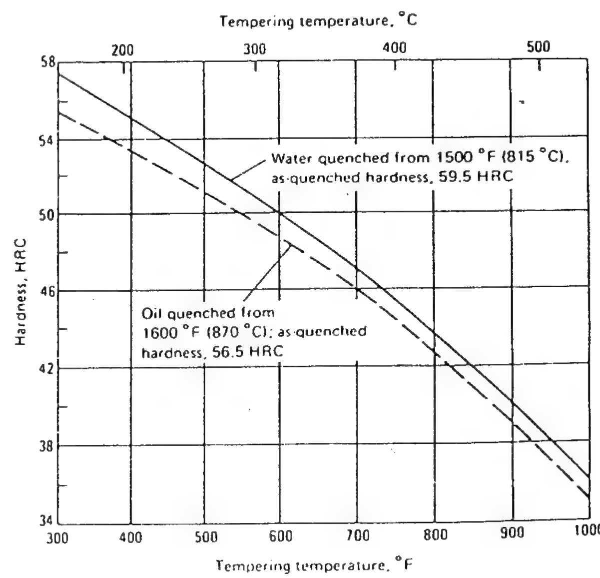


L2: Isothermal Transformation Diagram. Special-purpose tool steel containing 0.45 C, 0.70 Mn, 1.00 Cr, 0.20 V. Austenitizing temperature: 1650 °F (900 °C). (Source: Crucible Steel)

L2: Austenitizing Temperature Versus As-quenched Hardness. Special-purpose tool steel containing 0.45 C, 0.55 Mn, 0.95 Cr, 0.20 V. (Source: Bethlehem Steel)



L2: Tempering Temperature Versus Hardness. Effect of tempering and austenitizing temperature, and quenching medium on hardness of special-purpose tool steel. (Source: Universal-Cyclops)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

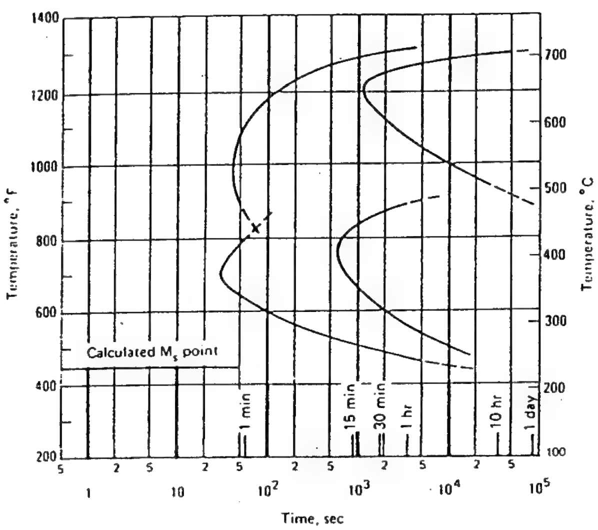
TYPE OF STEEL: L6
Low Alloy Special Purpose Tool Steel (L Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.70 C, 0.75 Cr, 1.50 Ni, 0.25 Mo (option.)

PART PREPARATION/FIXTURING:

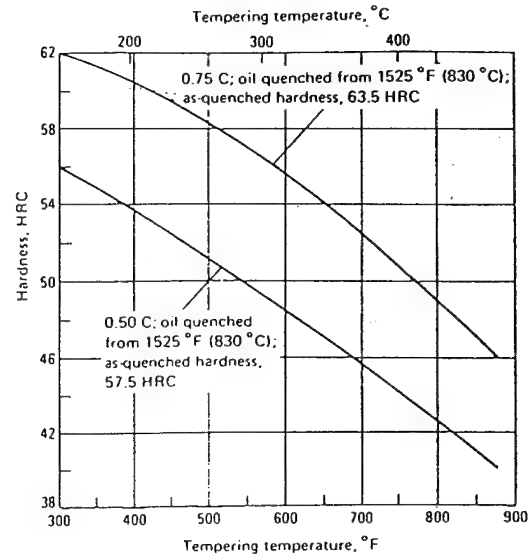
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1450 to 1550°F (10 to 30 minutes) if oil quenching *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Warm, agitated oil or polmer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 58 to 63 - Cool to 125°F in quench, Air cool to room temp. As quenched hardness may be slightly lower, but distortion will be held to a minimum - Temper immediately, after air cool - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

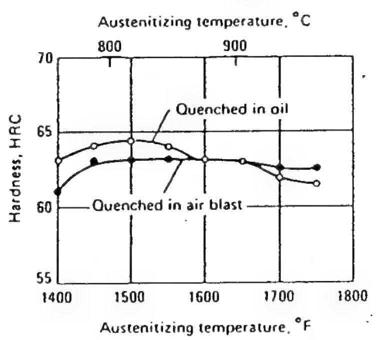
L6: Isothermal Transformation Diagram. Special-purpose tool steel containing 0.72 C, 0.35 Mn, 0.018 P, 0.010 S, 0.23 Si, 1.75 Ni, 0.94 Cr. Austenitizing temperature: 1525 °F (830 °C). (Source: Carpenter Steel)



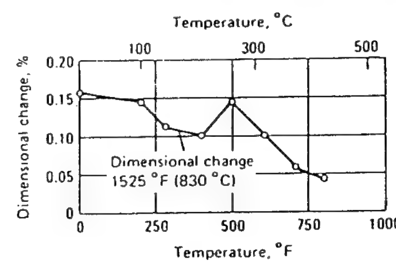
L6: Tempering Temperature Versus Hardness. Effect of tempering temperature and carbon content on the hardness. (Source: Universal-Cyclops)

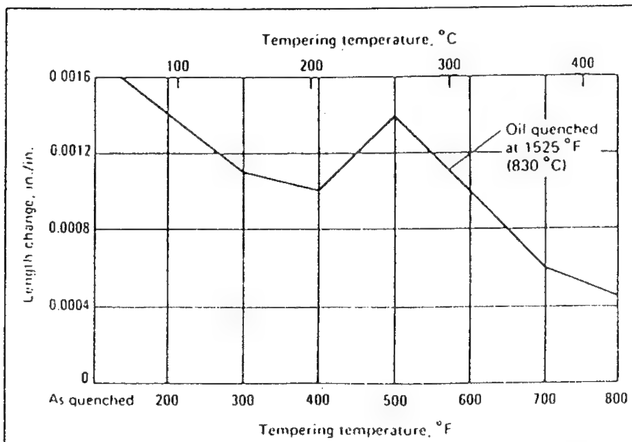


L6: Austenitizing Temperature and Quenchant Versus As-quenched Hardness. Effect of austenitizing temperature and quenching medium on the as-quenched hardness of a 1-in. diam by 5-in. specimen containing 0.75 C, 0.75 Mn, 0.90 Cr, 1.75 Ni, 0.35 Mo. (Source: Bethlehem Steel)



L6: Dimensional Change Versus Tempering Temperature. Effect of tempering temperature on dimensional change of special-purpose tool steel. (Source: Carpenter Steel)





L6: Length Change as a Function of Tempering Temperature. A ¾-in. round specimen of an L6 special-purpose tool steel containing 0.75 C, 0.35 Mn, 1.00 Cr, 1.75 Ni. (Source: *Tool Steels*, American Society for Metals, 1980)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

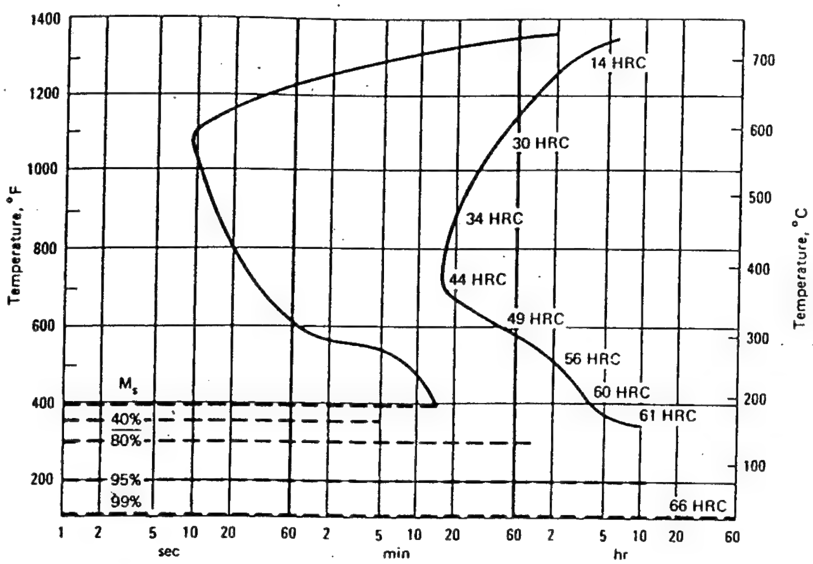
HEAT TREAT DATA SHEET

TYPE OF STEEL: O1
Oil Hardening Cold Work Tool Steel (O Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.90 C, 1.00 Mn, 0.50 Cr, 0.50 W

PART PREPARATION/FIXTURING:

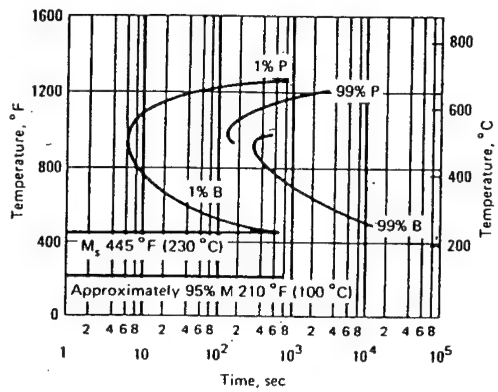
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1450 to 1500°F (10 to 30 minutes) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Oil, or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 63 to 65 - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

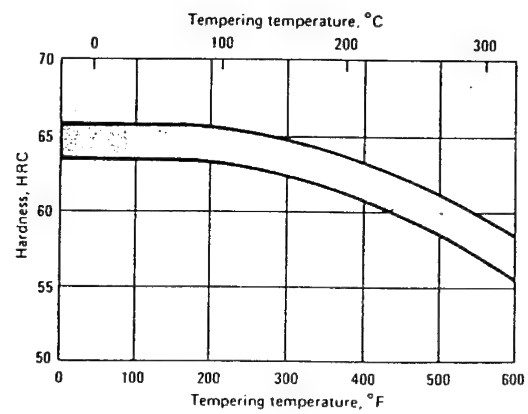


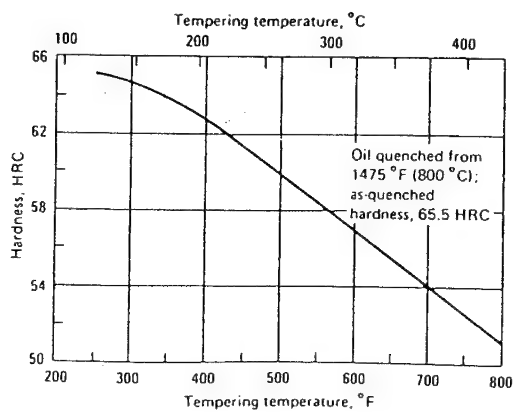
O1: Isothermal Transformation Diagram. Composition: 0.85 C, 1.18 Mn, 0.26 Si, 0.50 Cr, 0.44 W. Critical temperature (Ac_1): 1370 °F (745 °C). Prior condition: annealed. (Source: *Tool Steels*, American Society for Metals, 1980)

O1: Isothermal Transformation Diagram. Swedish grade showing percent pearlite and bainite as a function of time and transformation temperature. (Source: Uddeholm Steels)



O1: Hardness Versus Tempering Temperature. Austenitized at 1450 to 1500 °F (790 to 815 °C). Band approximately 2 HRC points wide. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)





O1: Hardness Versus Tempering Temperature. Austenitized at 1475 °F (800 °C). (Source: Universal-Cyclops)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

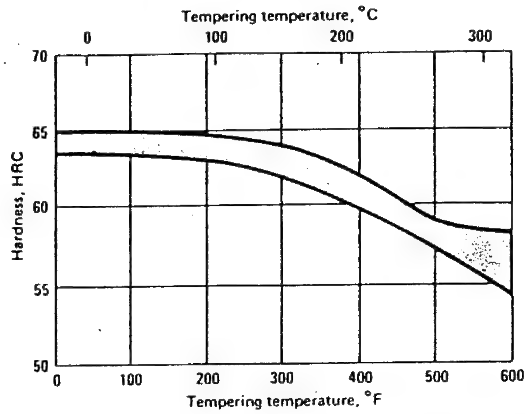
TYPE OF STEEL: O2
Oil Hardening Cold Work Tool Steel (O Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.90 C, 1.60 Mn

PART PREPARATION/FIXTURING:

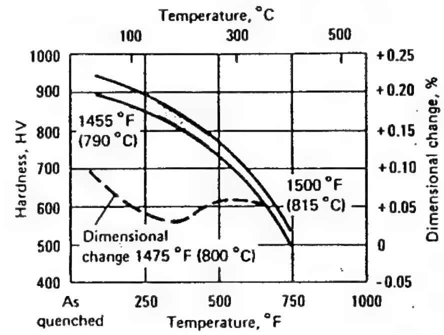
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1400 to 1475°F (5 to 20 minutes) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Oil, or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 63 to 65 - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

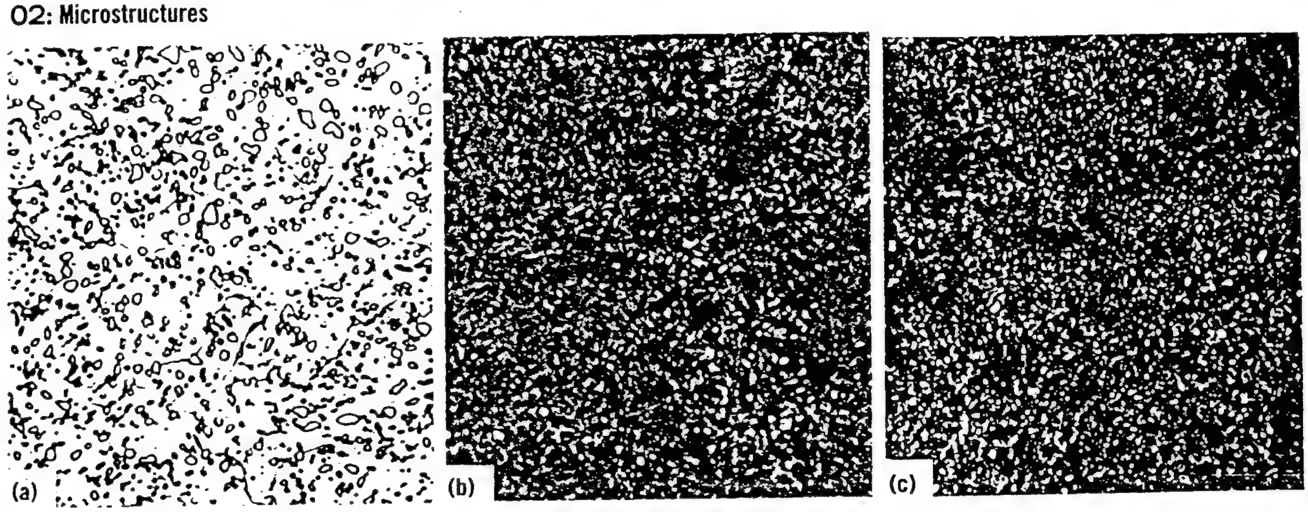
O2: Hardness Versus Tempering Temperature. Austenitized at 1425 to 1475 °F (775 to 800 °C) and tempered for 1 hr. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



O2: Dimensional Change Versus Tempering Temperature. Austenitized at 1475 °F (800 °C). Band shows approximate upper and lower hardness limits after tempering steel and austenitizing at 1455 °F (790 °C) and 1500 °F (815 °C). Shaded portion, optimum tempering range. (Sources: British Steel and Carpenter Steel)



O2: Microstructures



(a) Nital, 1000X. Annealed by heating to 1340 °F (725 °C), holding for 1 hr per inch of section thickness and furnace cooling. Spheroidal carbide in a matrix of ferrite. (b) Nital, 1000X. Austenitized 15 min at 1475 °F (800 °C), quenched in oil. Some spheroidal carbide (white dots) in a matrix of untempered martensite. (c) Nital, 1000X. Austenitized and quenched same as (b), then tempered 1 hr at 350 °F (175 °C). Some spheroidal carbide (white dots) in tempered martensite. (Source: *Metals Handbook*, 8th ed., Vol 7, American Society for Metals, 1972)

O6

Chemical Composition. AISI: Nominal. 1.45 C, 0.80 Mn, 1.00 Si, 0.25 Mo. UNS: 1.25 to 1.55 C, 0.30 Cr max, 0.30 to 1.10 Mn, 0.20 to 0.30 Mo, 0.030 P max, 0.030 S max, 0.55 to 1.50 Si

Similar Steels (U.S. and/or Foreign). UNS T31506; AISI O-6; ASTM A681 (O-6); FED QQ-T-570 (O-6); SAE J437 (O6), J438 (O6)

Characteristics. Generally low distortion with high safety in hardening. Contains graphite and is relatively deep hardening with high abrasion resistance. Not readily obtainable in a variety of sizes

Forging. Start forging at 1800 to 1950 °F (980 to 1065 °C). Do not forge below 1500 °F (815 °C)

Recommended Heat Treating Practice

Normalizing. Heat to 1600 °F (870 °C). Holding time, after uniform through heating, varies from about 15 min for small sections to about 1 hr for large sections. Work is cooled from temperature in still air

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: O6
Oil Hardening Cold Work Tool Steel (O Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.45 C, 0.800 Mn, 1.00 Si, 0.25 Mo

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1450 to 1500°F (10 to 30 minutes) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Oil, or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 63 to 65 - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

Annealing. Heat to 1410 to 1450 °F (765 to 790 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies from about 1 hr for light sections and small furnace charges to about 4 hr for heavy sections and large charges. For pack annealing, hold for 1 hr per inch of pack cross section. Cool at a maximum rate of 10 °F (6 °C) per hour. From 1300 °F (705 °C) to 1000 °F (540 °C) cool at a rate of 25 °F (14 °C) per hour. Maximum rate not critical after cooling below 1000 °F (540 °C). Typical annealed hardness, 183 to 217 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) for 1 hr per inch of cross section (minimum 1 hr). Cool in air

Hardening. Preheat slowly to 1200 °F (650 °C). Austenitize at 1450 to 1500 °F (790 to 815 °C) for 10 to 30 min, then quench in oil. Quenched hardness, 63 to 65 HRC

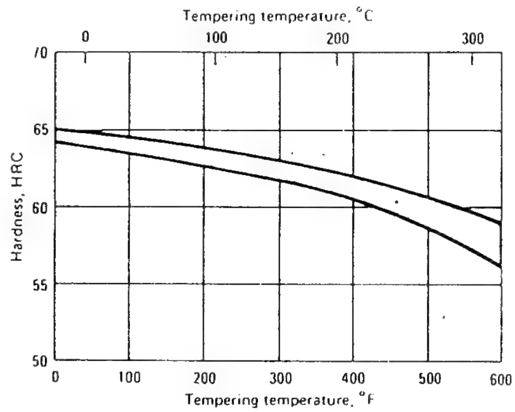
Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) for 20 to 30 min. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

Tempering. Temper at 350 to 600 °F (175 to 315 °C) for a corresponding approximate tempered hardness of 63 to 58 HRC

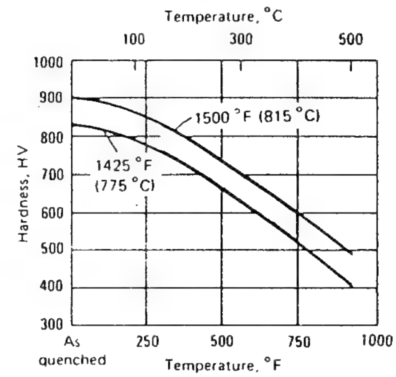
Recommended Processing Sequence

- Normalize
- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size

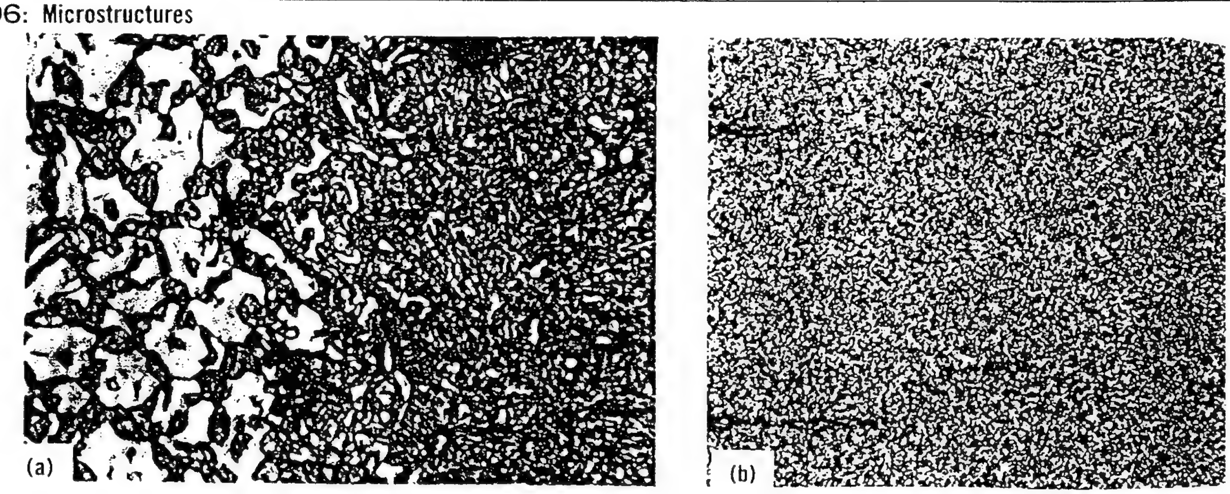
O6: Hardness Versus Tempering Temperature. Austenitized at 1450 to 1500 °F (790 to 815 °C) and tempered 1 hr. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



O6: Hardness Versus Tempering Temperature. Hardness of a British grade of O6 tool steel as a function of austenitizing and tempering temperatures. The band represents upper and lower limits of hardness, and the shaded portion indicates the optimum tempering range. (Source: British Steel)



O6: Microstructures



(a) 3% nital, 1000X. Austenitized at 1475 °F (800 °C), oil quenched, tempered at 325 °F (165 °C). Partial-to-total decarburization (left), carbon-lean martensite (light gray), tempered martensite (dark gray), and graphite (black). **(b)** Nital, 100X. Austenitized at 1450 °F (790 °C) for 50 min, oil quenched, tempered at 400 °F (205 °C) for 2 hr. Longitudinal section. Black streaks are elongated particles of graphite (Source: Metals Handbook, 8th ed., Vol 7, American Society for Metals, 1972)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **O7**
Oil Hardening Cold Work Tool Steel (O Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.20 C, 1.75 W, 0.75 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1450 to 1525°F (10 to 30 minutes) if water quenching 1500 to 1625°F (10 to 30 minutes) if oil quenching note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil, Polymer, or Water
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 64 to 66 (water) HRC 64 to 66 (oil) - If water quenching, temper immediately after parts reach 140°F, to prevent cracking - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

quenched hardness of 64 to 66 HRC. To prevent cracking, do not let tool cool below 140 °F (60 °C) and temper immediately. If oil quench is used, austenitize at 1500 to 1625 °F (815 to 885 °C) for 10 to 30 min and quench in oil for a quenched hardness of 64 to 66 HRC. Sections larger than 1½ in. will be softer

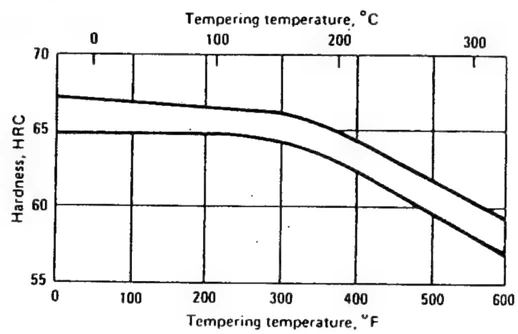
Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) for 20 to 30 min. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

Tempering. Temper at 350 to 550 °F (175 to 290 °C) for a corresponding approximate tempered hardness of 64 to 58 HRC

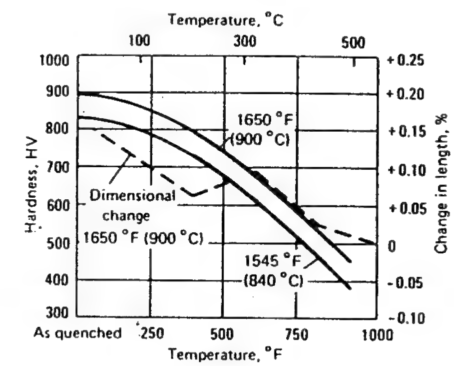
Recommended Processing Sequence

- Normalize
- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size

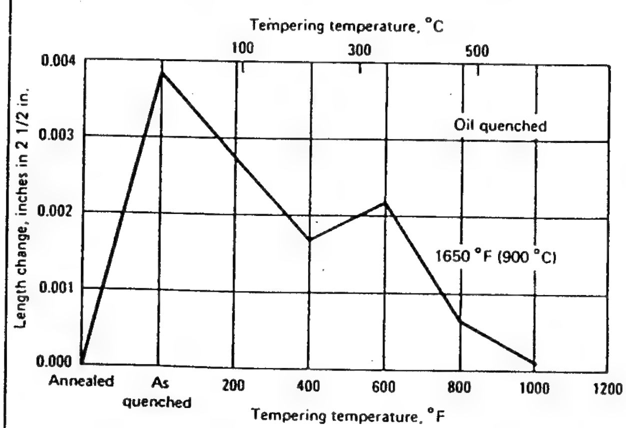
O7: Hardness Versus Tempering Temperature. Hardness as a function of austenitizing and tempering temperatures. Large uniform sections were austenitized at 1475 to 1525 °F (800 to 830 °C) and water quenched. Other sections were austenitized at 1525 to 1600 °F (830 to 870 °C) and oil quenched. Duration of tempering was 1 hr. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



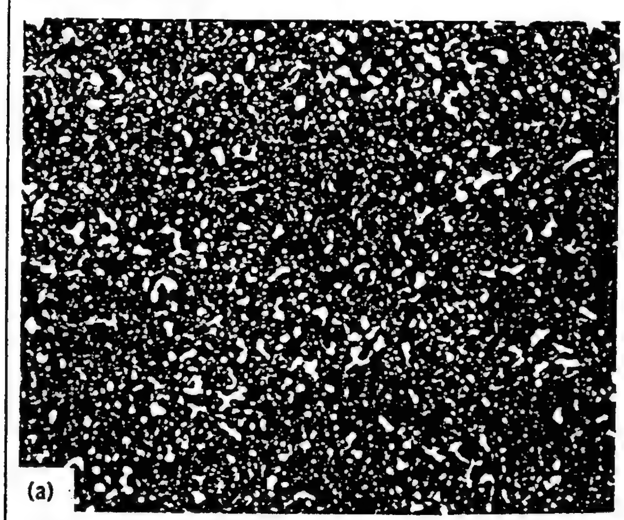
O7: Dimensional Change Versus Tempering Temperature. Austenitized at 1650 °F (900 °C). Band shows approximate upper and lower hardness limits after tempering the steel when austenitized at 1545 °F (840 °C) and 1650 °F (900 °C). Shaded portion indicates optimum tempering range. (Sources: Bain and Grossman and *Tool Steels*, American Society for Metals, 1980)



O7: Length Changes Versus Tempering Temperature. Quenched from the indicated temperature. (Sources: Bain and Grossman and Allegheny Ludlum Industries)



O7: Microstructure



Nital, 1000X. Austenitized at 1625 °F (885 °C), quenched in oil, and then tempered at 400 °F (205 °C). Structure consists of undissolved particles of carbide (white) in a matrix of tempered martensite. (Source: *Metals Handbook*, 8th ed., Vol 7, American Society for Metals, 1972)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **P2**
Mold Steel (P Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.07 C, 0.20 Mo, 2.00 Cr, 0.50 Ni

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1525 to 1550°F (15 minutes) *** note: *time at temp.*
STEP QUENCH:	N/A
QUENCH:	Warm, agitated oil or polmer or in brine
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 65 - ***: must be carburized in order to be hardened - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

Mold Steels (P Series)

The P series steels are unique in that their carbon content ranges from very low to medium and their alloy content from about 1.5% to a maximum of about 5%. Depending on composition, P steels can be used for plastic molds, and, to a lesser extent, for die-casting dies. The hardening process is explained in detail in the paragraphs describing each P steel. P21 is an exception, hardened by solution treating and aging. The low-carbon grades may be carburized, and the medium-carbon grades are sometimes nitrided.

The annealing of these steels often is neither necessary nor desirable, because a fully annealed structure is more difficult to machine. The carburizing and nitriding processes used follow the standard practices for other carbon or low-alloy steels. The heat treatment of P series steels closely resembles the practices applied to many carbon and low-alloy steels and has little similarity to the methods used with the higher alloyed tool steels, especially those with high carbon contents. Details of heat treating the various P steels are covered in the following paragraphs.

P2

Chemical Composition. AISI: Nominal. 0.07 C, 0.20 Mo, 2.00 Cr, 0.50 Ni. UNS: 0.10 C max, 0.75 to 1.25 Cr, 0.10 to 0.40 Mn, 0.15 to 0.40 Mo, 0.10 to 0.50 Ni, 0.03 P max, 0.03 S max, 0.10 to 0.40 Si

Similar Steels (U.S. and/or Foreign). UNS T51602; ASTM A681(P-2)

Characteristics. A low-carbon grade with good hobbing characteristics. Contains chromium and molybdenum for hardenability after carburizing, and nickel to improve core strength. Full hardness is usually obtained by oil quenching, which minimizes distortion. Rated medium in depth of hardening, low in distortion in heat treating, low in resistance to softening at elevated temperature, and high in resistance to decarburization

Forging. Start forging at 1850 to 2050 °F (1010 to 1120 °C), and do not forge below 1550 °F (845 °C)

Recommended Heat Treating Practice

Normalizing. Not necessary to normalize

Annealing. Heat to 1350 to 1500 °F (730 to 815 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies from about 1 hr for light sections and small furnace charges, to about 4 hr for heavy sections and large charges. For pack annealing, hold for 1 hr per inch of cross section. Avoid surface carburization, which drastically impairs metal flow when hobbing. Cool at a maximum rate of 40 °F (22 °C) per hour. The maximum rate is not critical after cooling to below 1000 °F (540 °C). Typical annealed hardness, 103 to 123 HB

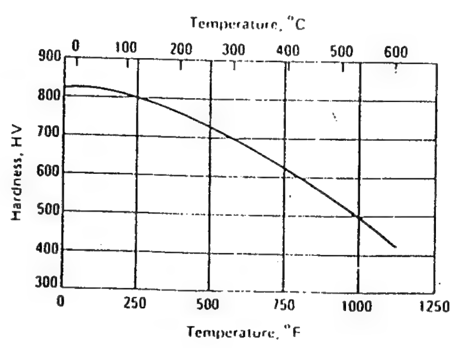
Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Carburize at 1650 to 1700 °F (900 to 925 °C) to desired case depth. Austenitize at 1525 to 1550 °F (830 to 845 °C). Hold at austenitizing temperature for 15 min once the temperature is uniform throughout the tool. Quench in warm, agitated oil or in brine. Approximate quenched hardness, 62 to 65 HRC

Tempering. Temper at 350 to 500 °F (175 to 260 °C). Approximate hardness of the case as it corresponds to tempering temperature, 64 to 58 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional, between and after final hobbing)
- Finish machine
- Carburize
- Harden
- Quench
- Temper
- Final grind and polish



P2: Hardness Versus Tempering Temperature. Tempered surface hardness of a P2 tool steel (carburized case) carburized at 1700 °F (925 °C) for 8 hr and quenched in oil. (Source: Crucible Steel)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: P3
Mold Steel (P Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.10 C, 0.60 Cr, 1.25 Ni

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1475 to 1525°F (15 minutes) *** *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Warm, agitated oil or polmer or in brine
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 64 - ***: must be carburized in order to be hardened - Tempering parameters for P2 are applicable, (approx.) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

Mold Steels (P Series)

The P series steels are unique in that their carbon content ranges from very low to medium and their alloy content from about 1.5% to a maximum of about 5%. Depending on composition, P steels can be used for plastic molds, and, to a lesser extent, for die-casting dies. The hardening process is explained in detail in the paragraphs describing each P steel. P21 is an exception, hardened by solution treating and aging. The low-carbon grades may be carburized, and the medium-carbon grades are sometimes nitrided.

The annealing of these steels often is neither necessary nor desirable, because a fully annealed structure is more difficult to machine. The carburizing and nitriding processes used follow the standard practices for other carbon or low-alloy steels. The heat treatment of P series steels closely resembles the practices applied to many carbon and low-alloy steels and has little similarity to the methods used with the higher alloyed tool steels, especially those with high carbon contents. Details of heat treating the various P steels are covered in the following paragraphs.

P2

Chemical Composition. AISI: Nominal. 0.07 C, 0.20 Mo, 2.00 Cr, 0.50 Ni. UNS: 0.10 C max, 0.75 to 1.25 Cr, 0.10 to 0.40 Mn, 0.15 to 0.40 Mo, 0.10 to 0.50 Ni, 0.03 P max, 0.03 S max, 0.10 to 0.40 Si

Similar Steels (U.S. and/or Foreign). UNS T51602; ASTM A681(P-2)

Characteristics. A low-carbon grade with good hobbing characteristics. Contains chromium and molybdenum for hardenability after carburizing, and nickel to improve core strength. Full hardness is usually obtained by oil quenching, which minimizes distortion. Rated medium in depth of hardening, low in distortion in heat treating, low in resistance to softening at elevated temperature, and high in resistance to decarburization

Forging. Start forging at 1850 to 2050 °F (1010 to 1120 °C), and do not forge below 1550 °F (845 °C)

Recommended Heat Treating Practice

Normalizing. Not necessary to normalize

Annealing. Heat to 1350 to 1500 °F (730 to 815 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies from about 1 hr for light sections and small furnace charges, to about 4 hr for heavy sections and large charges. For pack annealing, hold for 1 hr per inch of cross section. Avoid surface carburization, which drastically impairs metal flow when hobbing. Cool at a maximum rate of 40 °F (22 °C) per hour. The maximum rate is not critical after cooling to below 1000 °F (540 °C). Typical annealed hardness, 103 to 123 HB

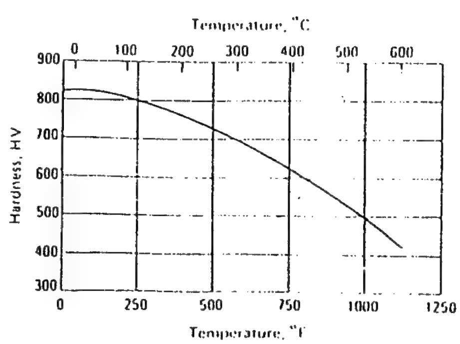
Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Carburize at 1650 to 1700 °F (900 to 925 °C) to desired case depth. Austenitize at 1525 to 1550 °F (830 to 845 °C). Hold at austenitizing temperature for 15 min once the temperature is uniform throughout the tool. Quench in warm, agitated oil or in brine. Approximate quenched hardness, 62 to 65 HRC

Tempering. Temper at 350 to 500 °F (175 to 260 °C). Approximate hardness of the case as it corresponds to tempering temperature, 64 to 58 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional, between and after final hobbing)
- Finish machine
- Carburize
- Harden
- Quench
- Temper
- Final grind and polish



P2: Hardness Versus Tempering Temperature. Tempered surface hardness of a P2 tool steel (carburized case) carburized at 1700 °F (925 °C) for 8 hr and quenched in oil. (Source: Crucible Steel)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **P4**
Mold Steel (P Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.07 C, 0.75 Mo, 5.00 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1775 to 1825°F (15 minutes) *** *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Warm, agitated oil, polymer, or Fluidized Bed Quench Bath
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 65 - ***: must be carburized in order to be hardened - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

P4

Chemical Composition. **AISI:** Nominal. 0.07 C, 0.75 Mo, 5.00 Cr. **UNS:** 0.12 C max, 4.00 to 5.25 Cr, 0.20 to 0.60 Mn, 0.40 to 1.00 Mo, 0.03 P max, 0.03 S max, 0.10 to 0.40 Si

Similar Steels (U.S. and/or Foreign). UNS T51604; ASTM A681(P-4); (W. Ger.) DIN 1.2341

Characteristics. Has the highest hardenability of the hobbing grades of P tool steels and can be considered the mold steel equivalent to the medium-alloy cold work die steel A2. Can be air hardened for minimum distortion or oil quenched to avoid surface scaling. Has the highest wear resistance and softening resistance at elevated temperatures of any of the mold steels. Rates high in depth of hardening, very low in distortion in heat treating, with high resistance to decarburization

Forging. Start forging at 1850 to 2050 °F (1010 to 1120 °C), and do not forge below 1600 °F (870 °C)

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat to 1600 to 1650 °F (870 to 900 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies from about 1 hr for light sections and small furnace charges to about 4 hr for heavy sections and large charges. For pack annealing, hold for 1 hr per inch of cross section. Avoid surface carburization which drastically impairs metal flow when hobbing. Cool at a maximum rate of 25 °F (14 °C) per hour. The maximum rate is not critical after cooling to below 1000 °F (540 °C). Typical annealed hardness, 116 to 128 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Carburize at 1775 to 1825 °F (970 to 995 °C) to desired case depth. Harden at 1775 to 1825 °F (970 to 995 °C) by holding at temperature 15 min once the temperature is uniform throughout the tool. Quench in air or oil. This grade may also be quenched in hot salt at 1000 to 1200 °F (540 to 650 °C) to prevent scaling of cavity. Cool in air as soon as temperature is uniform throughout the tool. Approximate quenched hardness, 62 to 65 HRC

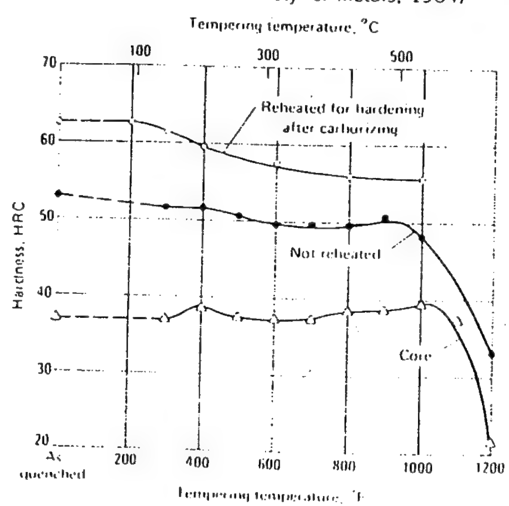
Stabilizing. Optional. Low temperature treatment may increase surface hardness. It is safer to stress relieve temper at 300 to 320 °F (150 to 160 °C) for a short period after refrigerating at −120 °F (−85 °C)

Tempering. Temper at 350 to 900 °F (175 to 480 °C). Approximate surface hardness as it corresponds to tempering temperature, 64 to 58 HRC

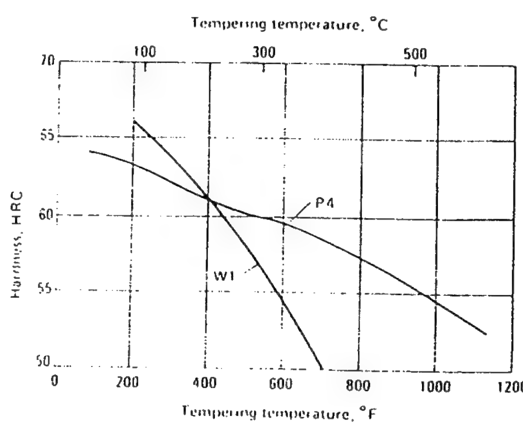
Recommended Processing Sequence

- Rough machine
- Stress relieve (optional, between and after last hobbing operation)
- Hob
- Carburize
- Harden
- Quench
- Stabilize (optional)
- Temper
- Final grind and polish

P4: Tempering Characteristics — Carburized Case and Core. ○: P4 carburized in hardwood charcoal at 1675 to 1700 °F (910 to 925 °C) for 8 hr, air cooled in pack, reheated at 1725 to 1750 °F (940 to 955 °C), cooled in air, and tempered. ●: P4 carburized in cast iron chips at 1725 to 1750 °F (940 to 955 °C), removed from pack, cooled in air and tempered. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



P4: Tempering Temperature Versus Carburized Surface Hardness. P4 compared to W1. Both carburized at 1700 °F (925 °C) for 8 hr in charcoal powder, and quenched in oil. (Source: Uddeholm Steel)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: P5
Mold Steel (P Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.10 C, 2.25 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1550 to 1600°F (15 minutes) *** note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Warm, agitated oil,or polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 62 to 65 - ***: must be carburized in order to be hardened - Tempering parameters for P2 are applicable, (approx.) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

Mold Steels (P Series)

The P series steels are unique in that their carbon content ranges from very low to medium and their alloy content from about 1.5% to a maximum of about 5%. Depending on composition, P steels can be used for plastic molds, and, to a lesser extent, for die-casting dies. The hardening process is explained in detail in the paragraphs describing each P steel. P21 is an exception, hardened by solution treating and aging. The low-carbon grades may be carburized, and the medium-carbon grades are sometimes nitrided.

The annealing of these steels often is neither necessary nor desirable, because a fully annealed structure is more difficult to machine. The carburizing and nitriding processes used follow the standard practices for other carbon or low-alloy steels. The heat treatment of P series steels closely resembles the practices applied to many carbon and low-alloy steels and has little similarity to the methods used with the higher alloyed tool steels, especially those with high carbon contents. Details of heat treating the various P steels are covered in the following paragraphs.

P2

Chemical Composition. AISI: Nominal. 0.07 C, 0.20 Mo, 2.00 Cr, 0.50 Ni. UNS: 0.10 C max, 0.75 to 1.25 Cr, 0.10 to 0.40 Mn, 0.15 to 0.40 Mo, 0.10 to 0.50 Ni, 0.03 P max, 0.03 S max, 0.10 to 0.40 Si

Similar Steels (U.S. and/or Foreign). UNS T51602; ASTM A681(P-2)

Characteristics. A low-carbon grade with good hobbing characteristics. Contains chromium and molybdenum for hardenability after carburizing, and nickel to improve core strength. Full hardness is usually obtained by oil quenching, which minimizes distortion. Rated medium in depth of hardening, low in distortion in heat treating, low in resistance to softening at elevated temperature, and high in resistance to decarburization

Forging. Start forging at 1850 to 2050 °F (1010 to 1120 °C), and do not forge below 1550 °F (845 °C)

Recommended Heat Treating Practice

Normalizing. Not necessary to normalize

Annealing. Heat to 1350 to 1500 °F (730 to 815 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies from about 1 hr for light sections and small furnace charges, to about 4 hr for heavy sections and large charges. For pack annealing, hold for 1 hr per inch of cross section. Avoid surface carburization, which drastically impairs metal flow when hobbing. Cool at a maximum rate of 40 °F (22 °C) per hour. The maximum rate is not critical after cooling to below 1000 °F (540 °C). Typical annealed hardness, 103 to 123 HB

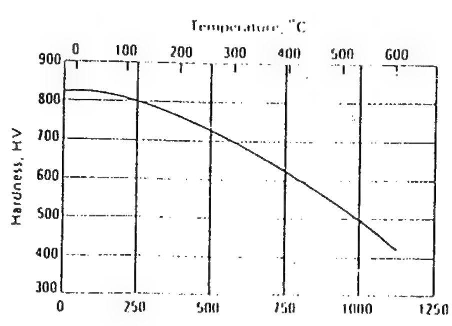
Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Carburize at 1650 to 1700 °F (900 to 925 °C) to desired case depth. Austenitize at 1525 to 1550 °F (830 to 845 °C). Hold at austenitizing temperature for 15 min once the temperature is uniform throughout the tool. Quench in warm, agitated oil or in brine. Approximate quenched hardness, 62 to 65 HRC

Tempering. Temper at 350 to 500 °F (175 to 260 °C). Approximate hardness of the case as it corresponds to tempering temperature, 64 to 58 HRC

Recommended Processing Sequence

- Rough machine
- Stress relieve (optional, between and after final hobbing)
- Finish machine
- Carburize
- Harden
- Quench
- Temper
- Final grind and polish



P2: Hardness Versus Tempering Temperature. Tempered surface hardness of a P2 tool steel (carburized case) carburized at 1700 °F (925 °C) for 8 hr and quenched in oil (Source: Crucible Steel)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: P6
Mold Steel (P Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.10 C, 1.50 Cr, 3.50 Ni

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1450 to 1500°F (15 minutes) *** note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Agitated oil,or polymer (large sections) Fluidized Bed Quench Bath (small sections)
1ST TEMPER:	350 to 450°F for hardness of HRC 61 to 58 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 60 to 62 - ***: must be carburized in order to be hardened - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

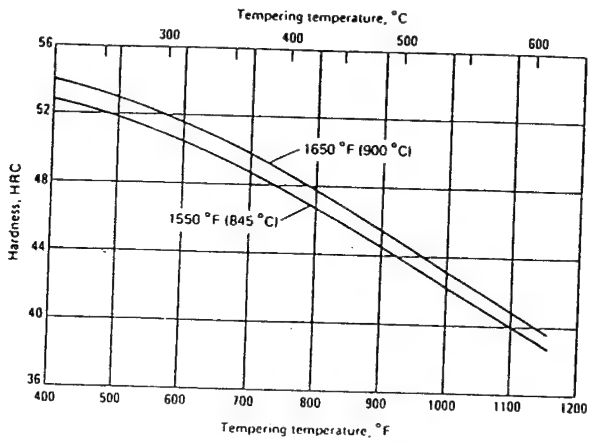
TYPE OF STEEL: P20
Mold Steel (P Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.35 C, 0.40 Mo, 1.70 Cr

PART PREPARATION/FIXTURING:

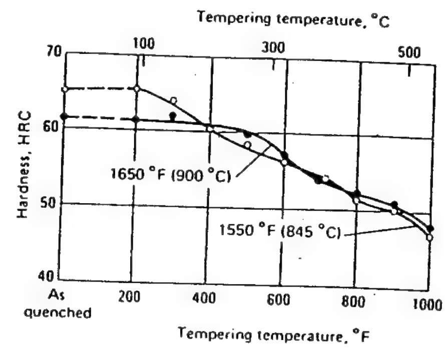
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1500 to 1600°F (15 minutes) ** note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Warm, agitated oil,or polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 61 to 64 - **: can be carburized in order to be hardened - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

P20: Hardness Versus Austenitizing and Tempering Temperatures. P20 austenitized at 1550 °F (845 °C) and oil quenched. As-quenched hardness, 53.5 HRC. When austenitized at 1650 °F (900 °C) and oil quenched, the as-quenched hardness is 54.5 HRC. (Source: Universal-Cyclops)



P20: Tempering Characteristics (Carburized). Surface hardness of P20 after heating at 1650 °F (900 °C) and 1550 °F (845 °C) for 2 hr in carburizing compound, oil quenching, and tempering. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1962)



P21

Chemical Composition. **AISI:** Nominal. 0.20 C, 4.00 Ni, 1.20 Al. **UNS:** 1.05 to 1.25 Al, 0.18 to 0.22 C, 0.20 to 0.30 Cr, 0.20 to 0.40 Mn, 4.00 to 4.25 Ni, 0.03 P max, 0.03 S max, 0.20 to 0.40 Si, 0.15 to 0.25 V

Similar Steels (U.S. and/or Foreign). UNS T51621; ASTM A681(P-21)

Characteristics. An age-hardening tool steel. When heat treating, a high-temperature tempering treatment is used to lower hardness and enable the cavity to be machined. Final hardening occurs during aging. This grade can be nitrided, but should not be carburized. Is deep hardening, with medium softening resistance at elevated temperatures, and high decarburization resistance

Forging. Start forging at 2000 to 2100 °F (1095 to 1150 °C), and do not forge below 1750 °F (955 °C)

Recommended Heat Treating Practice

Normalizing. Heat to 1650 °F (900 °C). After uniform through heating, holding time varies from about 15 min for small sections to about 1 hr for large sections. Work is cooled from temperature in still air

Annealing. Do not anneal

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Solution treat by heating slowly to 1300 to 1350 °F (705 to 730 °C) and holding for 60 min for small sections to 180 min for large sections. Do not preheat. Cool in air or quench in oil to accelerate cooling. Approximate hardness range, 24 to 28 HRC. After machining, age harden at 950 to 1025 °F (510 to 550 °C), holding at temperature for 20 hr for small sections and up to 24 hr for large sections. Approximate aged hardness, 40 to 30 HRC. This grade cannot be carburized, but may be nitrided by holding in a gas nitriding furnace containing ammonia for 20 to 24 hr at 950 °F (510 °C) to 975 °F (525 °C). Case depth will be approximately 0.006 to 0.008 in. (0.152 to 0.203 mm) with a hardness of 94 HR15N

Recommended Processing Sequence

- Normalize (if not purchased ready for solution treating)
- Solution treat
- Quench
- Rough machine
- Stress relieve (optional, below aging temperature such as 750 to 800 °F or 400 to 425 °C)
- Finish machine
- Age

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: P21
Mold Steel (P Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.20 C, 4.00 Ni, 1.20 Al

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
SOLUTION TREAT:	1300°F (60 minutes for small sections and 180 minutes for large sections) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath orwarm, agitated oil,or polymer
AGE HARDENING:	950 TO 1025°F (20 hours for small sections and 24 hours for large sections)

COMMENTS:

- Approx. As Quenched Hardness: HRC 24 to 28
- Approx. as Age Hardened Hardness: HRC 30 to 40
- Atmosphere for Solution Treating: 100% Nitrogen
- Atmosphere for Age Hardening: 100% Nitrogen
- This grade can not be carburized

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

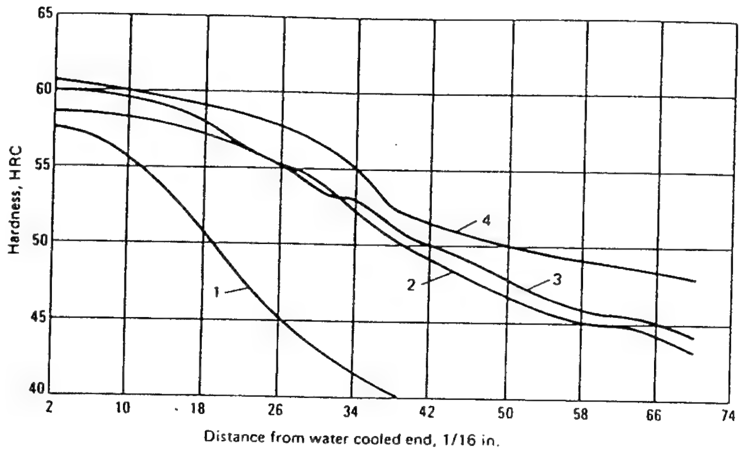
TYPE OF STEEL: **S1**
Shock Resisting Tool Steel (S Series)

CHEMICAL COMPOSITION: AISI: Nominal. 0.50 C, 2.50 W, 1.50 Cr

PART PREPARATION/FIXTURING:

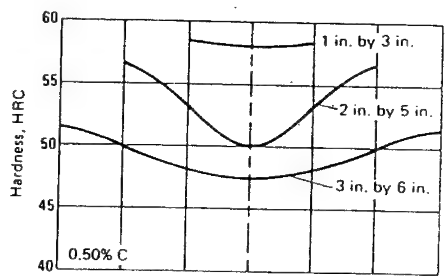
PROCESS PARAMETERS:

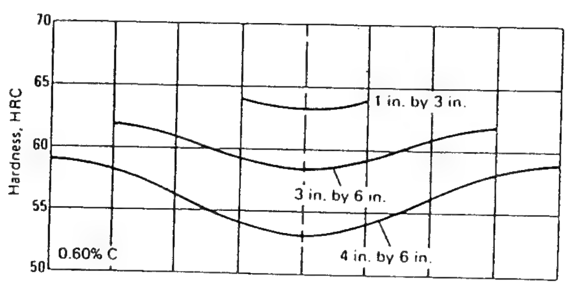
PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1650 to 1750°F (15 to 45 minutes) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 57 to 59 - Temper within 15 to 30 minutes of quenching, to prevent cracking. Time may vary with austenitizing temp., size and shape of parts. - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.



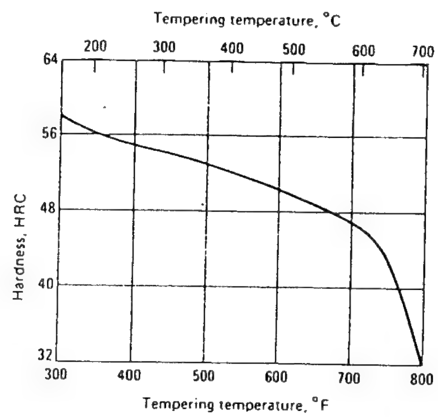
S1: End-Quench Hardenability. 1: S1 containing 0.53 C, 0.26 Si, 0.38 Mn, 1.42 Cr, 2.13 W. 2: S1 containing 0.54 C, 1.02 Si, 0.41 Mn, 1.40 Cr, 2,20 W. 3: S1 containing 0.51 C, 0.26 Si, 0.39 Mn, 1.43 Cr, 2.15 W, 0.51 Mo, 0.30 V. 4: S1 containing 0.52 C, 1.04 Si, 0.42 M, 1.46 Cr, 2.14 W, 0.53 Mo, 0.32 V. All austenitized at 1740 °F (950 °C). (Source: *Tool Steels*, American Society for Metals, 1980)

S1: Cross-Sectional Hardness. S1 containing 0.50% and 0.60% C, austenitized at 1700 °F (925 °C) and quenched in oil. (Source: Columbia Tool Steel)

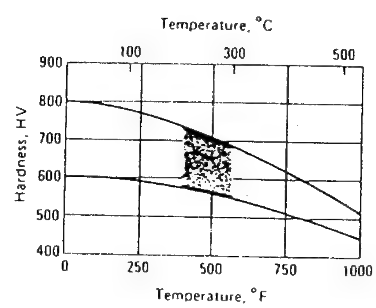




S1: Hardness Versus Tempering Temperature. S1 austenitized at 1750 °F (955 °C) and quenched in oil. As-quenched hardness, 59 HRC. (Source: Universal-Cyclops)



S1: Hardness Versus Tempering Temperature. Shaded portion shows optimum range for best combination of hardness and toughness. (Source: *Tool Steels*, American Society for Metals, 1980)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: S2
Shock Resisting Tool Steel (S Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.50 C, 1.00 Si, 0.50 Mo

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1550 to 1650°F (5 to 20 minutes) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Agitated Water or Brine
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 60 to 62 - Temper within 10 minutes of quenching, to prevent cracking - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

S2

Chemical Composition. **AISI:** Nominal. 0.50 C, 1.00 Si, 0.50 Mo. **UNS:** 0.40 to 0.55 C, 0.30 to 0.50 Mn, 0.30 to 0.60 Mo, 0.03 P max, 0.03 S max, 0.90 to 1.20 Si, 0.50 V max

Similar Steels (U.S. and/or Foreign). UNS T41902; ASTM A681 (S2); FED QQ-T-570(S2); SAE J437(S2); J438 (S2)

Characteristics. Among the most shock resistant of the S series. Has low safety in hardening because cracking in water or brine quenchants is possible. Overheating or oversoaking during austenitizing will lower ductility and promote grain growth. Will decarburize readily if not adequately protected

Forging. Start forging at 1850 to 2050 °F (1010 to 1120 °C), and do not forge below 1600 °F (870 °C)

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat to 1400 to 1450 °F (760 to 790 °C). Use lower limit for small sections, upper limit for large sections. Holding time varies from 1 hr for light sections and small furnace charges to 4 hr for large sections and large furnace charges. Cool at a maximum rate of 40 °F (22 °C) per hour. Maximum rate not critical after cooled to about 950 °F (510 °C). Typical annealed hardness, 192 to 217 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Heat slowly. Preheat at 1200 °F (650 °C). Austenitize at 1550 to 1650 °F (845 to 900 °C), hold for 5 to 20 min, then quench in brine or water. As-quenched hardness, 60 to 62 HRC

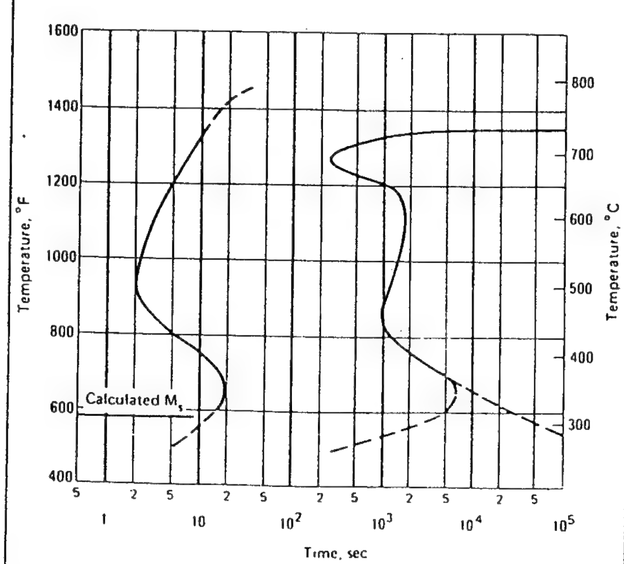
Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) briefly. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

Tempering. To prevent cracking, temper within 10 min, particularly if quenched in brine from 1650 °F (900 °C). Temper at 350 to 800 °F (175 to 425 °C). Approximate tempered hardness as it corresponds to tempering temperature, 60 to 50 HRC

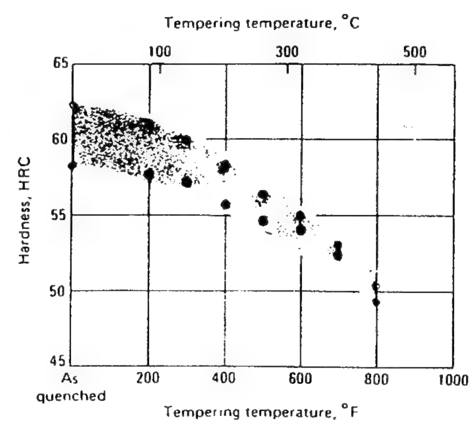
Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size

S2: Isothermal Transformation Diagram. S1 containing 0.50 C, 0.35 Mn, 0.018 P, 0.013 S, 1.0 Si, 0.19 Ni, 0.11 Cr, 0.50 Mo. Austenitized at 1550 °F (845 °C). Grain size, 8. (Source: Carpenter Steel)



S2: Hardness Versus Tempering Temperature. ○: S2 containing 0.50 C, 1.10 Si, 0.50 Mo, 0.20 V, quenched in water from 1575 °F (860 °C). ●: S2 containing 0.50 C, 1.10 Si, 0.50 Mo, 0.20 V, quenched in oil from 1650 °F (900 °C). (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

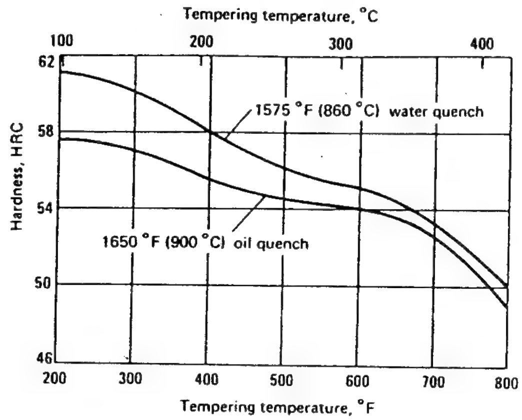
TYPE OF STEEL: S5
Shock Resisting Tool Steel (S Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.55 C, 0.80 Mn, 2.00 Si, 0.40 Mo

PART PREPARATION/FIXTURING:

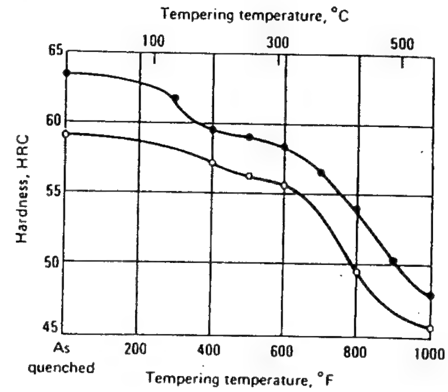
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1400°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1600 to 1700°F (5 to 20 minutes) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 57 to 59 - Temper within 15 to 30 minutes of quenching, to prevent cracking. Time may vary with austenitizing temperature. - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

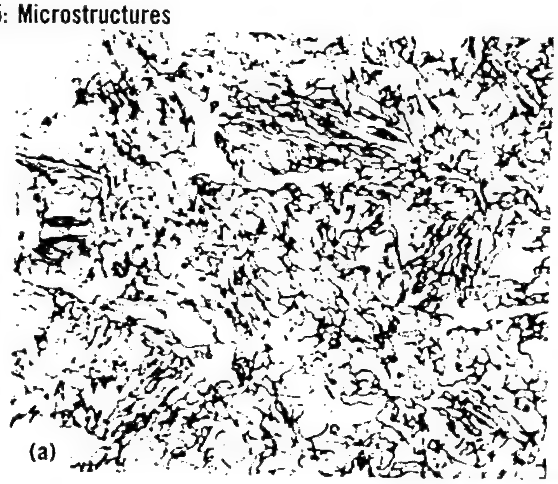
S5: Hardness Versus Tempering Temperature. S5 water quenched from 1575 °F (860 °C). As-quenched hardness, 62 HRC. S5 oil quenched from 1650 °F (900 °C). As-quenched hardness, 58 HRC. (Source: Universal-Cyclops)

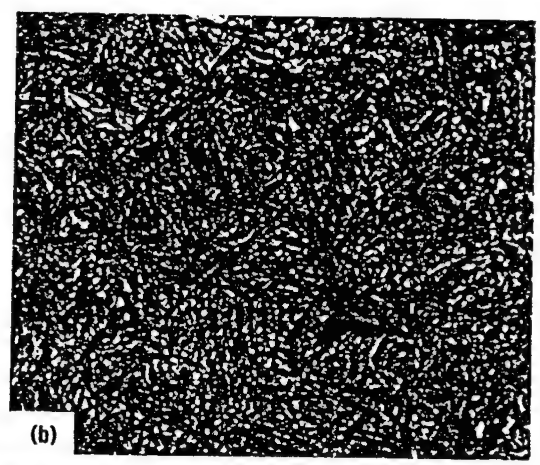


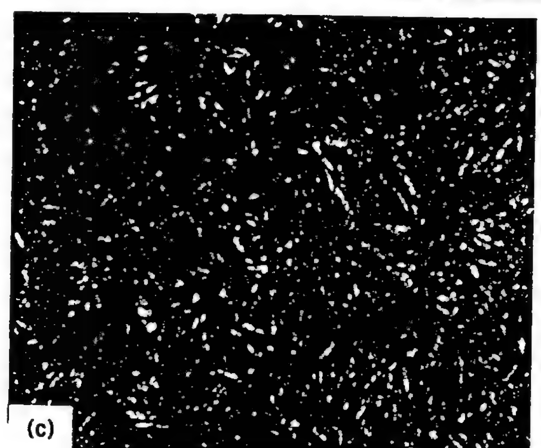
S5: Hardness Versus Tempering Temperature. ○: S5 containing 0.50 C, 0.70 Mn, 1.60 Si, 0.40 Mo, 0.12 V; quenched in oil from 1600 °F (870 °C). ●: S5 containing 0.60 C, 0.85 Mn, 2.00 Si, 0.25 Cr, 0.25 Mo, 0.20 V; quenched in oil from 1625 °F (885 °C). (Source: Allegheny Ludlum Industries)



S5: Microstructures


(a)


(b)


(c)

(a) Nital, 1000X. Normalized by austenitizing at 1700 °F (925 °C) for 1 hr and air cooling. Mixture of martensite and coarse pearlite.
(b) 2% nital, 1000X. Austenitized at 1650 °F (900 °C) and oil quenched. Steel not tempered. Fine untempered martensite. See (c).
(c) 2% nital, 1000X. Austenitized at 1650 °F (900 °C), oil quenched, and tempered at 750 °F (400 °C). Fine tempered martensite.
(Source: *Metals Handbook*, 8th ed., Vol 7, American Society for Metals, 1972)

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: S6
Shock Resisting Tool Steel (S Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.45 C, 1.40 Mn, 2.25 Si, 0.40 Mo, 1.50 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1400°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1675 to 1750°F (10 to 30 minutes) *note: time at temp.*
STEP QUENCH:	N/A
QUENCH:	Oil or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 56 to 60 - Temper immediately after parts reach room temperature. - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

S6

Chemical Composition. AISI: Nominal. 0.45 C, 1.40 Mn, 2.25 Si, 0.40 Mo, 1.50 Cr. **UNS:** 0.40 to 0.50 C, 1.20 to 1.50 Cr, 1.20 to 1.50 Mn, 0.30 to 0.50 Mo, 0.03 P max, 0.03 S max, 2.00 to 2.50 Si, 0.20 to 0.40 V

Similar Steels. UNS T41906; ASTM A681(S-6); FED QQ-T-570 (S-6)

Characteristics. High safety in hardening. Will decarburize readily if not adequately protected. One of the more highly alloyed grades, making it among the more expensive S series steels

Forging. Start forging at 1850 to 2050 °F (1010 to 1120 °C), and do not forge below 1600 °F (870 °C)

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat to 1475 to 1525 °F (800 to 830 °C). Use lower limit for small sections, upper limit for large sections. Holding time varies from 1 hr for light sections and small furnace charges to 4 hr for large sections and large furnace charges. Cool at a maximum rate of 25 °F (14 °C) per hour. Maximum rate not critical after cooling to about 950 °F (510 °C). Typical annealed hardness, 192 to 229 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Heat slowly. Preheat at 1400 °F (760 °C). Austenitize at 1675 to 1750 °F (915 to 955 °C). Hold for 10 to 30 min, then quench in oil. As-quenched hardness, 56 to 60 HRC

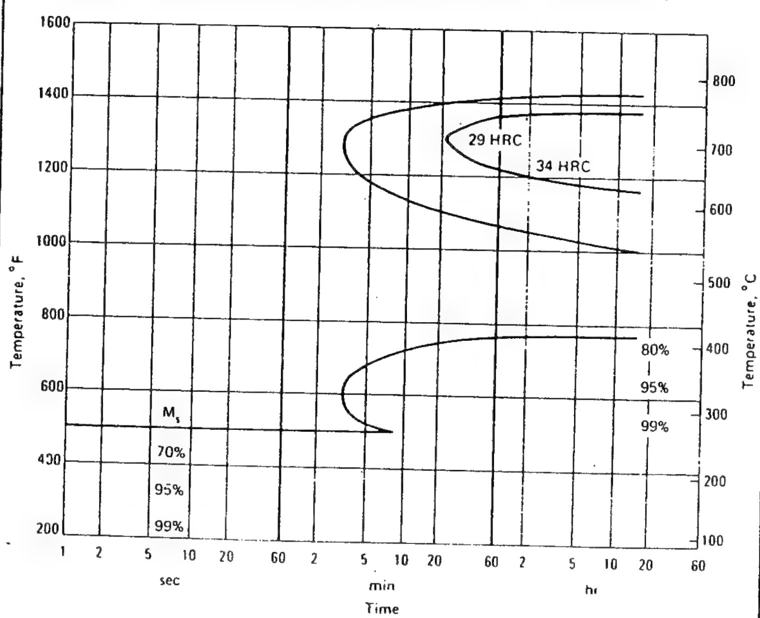
Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) briefly. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

Tempering. Temper at 400 to 600 °F (205 to 315 °C). Approximate tempered hardness as it corresponds to tempering temperature, 56 to 54 HRC

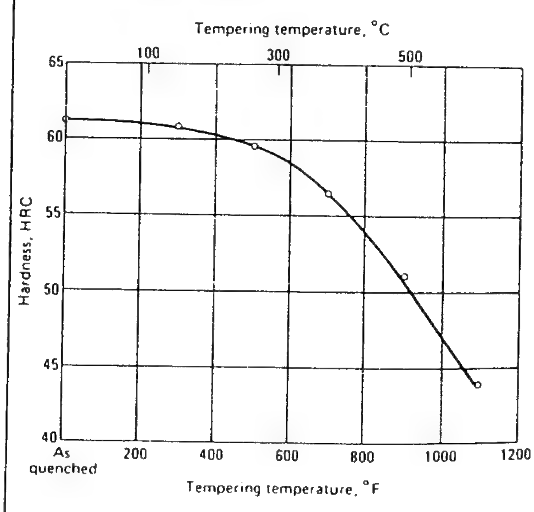
Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size

S6: Isothermal Transformation Diagram. S6 containing 0.43 C, 1.35 Mn, 2.25 Si, 1.35 Cr, 0.40 Mo and 0.30 V. Austenitized at 1700 °F (925 °C) and oil quenched. As-quenched hardness, 60 HRC. (Source: Crucible Steel)



S6: Hardness Versus Tempering Temperature. S6 containing 0.55 C, 0.97 Mn, 1.95 Si, 1.07 Mo, 0.25 V, 0.29 Cr. Austenitized at 1600 °F (870 °C) and quenched in oil. (Source: Teledyne VASCO)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: S7
Shock Resisting Tool Steel (S Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.50 C, 1.40 Mo, 3.25 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	1200 to1300°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1700 to 1750°F (15 to 45 minutes) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil, Polymer, or Fluidized Bed Quench Bath operating on nitrogen
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 60 to 61 - Temper immediately after parts reach room temperature. - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

S7

Chemical Composition. **AISI:** Nominal. 0.50 C, 1.40 Mo, 3.25 Cr. **UNS:** 0.45 to 0.55 C, 3.00 to 3.50 Cr, 0.20 to 0.80 Mn, 1.30 to 1.80 Mo, 0.03 P max, 0.03 S max, 0.20 to 1.00 Si, 0.20 to 0.30 V (optional)

Similar Steels. UNS T41907; ASTM A681 (S-7)

Characteristics. Has highest hardenability of the S series steels and maximum softening resistance at elevated temperatures. Has moderate resistance to decarburization and grain growth

Forging. Start forging at 1950 to 2050 °F (1065 to 1120 °C), and do not forge below 1700 °F (925 °C)

Recommended Heat Treating Practice

Normalizing. Do not normalize

Annealing. Heat to 1500 to 1550 °F (815 to 845 °C). Use lower limit for small sections, upper limit for large sections. Holding time varies from 1 hr for light sections and small furnace charges to 4 hr for large sections and large furnace charges. Cool at a maximum rate of 25 °F (14 °C) per hour. Maximum rate not critical after cooled to about 950 °F (510 °C). Typical annealed hardness, 187 to 223 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Heat slowly. Preheat at 1200 to 1300 °F (650 to 705 °C). When using an open furnace, austenitize at 1700 to 1750 °F (925 to 955 °C), hold for 15 to 45 min. For pack hardening, hold for 1/2 hr per inch of pack cross section. Quench in oil or air cool. As-quenched hardness, 60 to 61 HRC

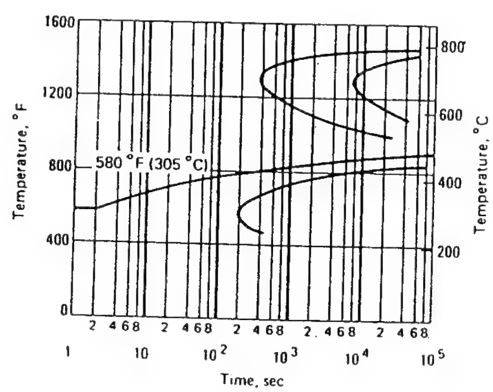
Stabilizing. Optional. For intricate shapes, stress relieve temper at 300 to 320 °F (150 to 160 °C) briefly. Refrigerate at −150 to −320 °F (−100 to −195 °C). Temper immediately after part reaches room temperature

Tempering. Temper at 400 to 1150 °F (205 to 620 °C). Approximate tempered hardness as it corresponds to tempering temperature, 57 to 45 HRC

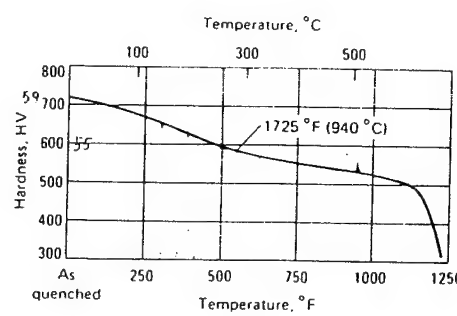
Recommended Processing Sequence

- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Stabilize (optional)
- Temper
- Final grind to size

S7: Isothermal Transformation Diagram. S7, austenitized at 1650 °F (900 °C). (Source: *Tool Steels,* American Society for Metals, 1980)



S7: Hardness Versus Tempering Temperature. S7, austenitized at 1725 °F (940 °C). (Source: *Tool Steels,* American Society for Metals, 1980)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **W1**
Water Hardening Tool Steel (W Series)
CHEMICAL COMPOSITION: AISI: Nominal. 0.60 to 1.40 C

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	Necessary only for intricate shapes or large sections where surface to center temps. would differ significantly
2ND PREHEAT:	N/A
AUSTENITIZE:	1400 to 1550°F (10 mins. for small sections and 30 mins. for large sections) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Agitated Water or Brine
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour at temperature
2ND TEMPER:	May be required
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 65 to 68 - Use upper end of Austenitizing Temperature range for low carbon contents and lower end of range for high carbon contents - Temper immediately after quenching, preferably before reaching room temp. (120°F is optimum) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

W1

Chemical Composition. AISI: Nominal. 0.60 to 1.40 C. **UNS:** 0.60 to 1.50 C, 0.15 Cr max, 0.20 Cu max, 0.10 to 0.40 Mn, 0.10 Mo max, 0.20 Ni max, 0.025 P max, 0.025 S max, 0.10 to 0.40 Si, 0.10 V max, 0.15 W max

Similar Steels (U.S. and/or Foreign). UNS T72301; ASTM A686 (W-1); SAE J437 (W108), (W109), (W110), (W112), J438 (W108), (W109), (W110), (W112)

Characteristics. Capable of hardening to high surface hardness and soft core which is useful in some shock applications. Low cost tool steels with fair to good wear resistance as carbon content increases. Water quenched with poor dimensional stability. Use limited to fairly uniform sections with minimum amount of stress raisers or quench cracking can occur

Forging. Start forging at 1800 to 1950 °F (980 to 1065 °C). Use upper temperature of range for 0.60 to 1.25 C, and lower temperature of range for 1.25 to 1.50 C. Do not forge below 1500 °F (815 °C)

Recommended Heat Treating Practice

Normalizing. For 0.60 to 0.75 C, heat to 1500 °F (815 °C); for 0.75 to 0.90 C, 1450 °F (790 °C); for 0.90 to 1.10 C, 1600 °F (870 °C); for 1.10 to 1.50 C, 1600 to 1700 °F (870 to 925 °C). After uniform through heating, holding time varies from about 15 min for small sections to about 1 hr for large sections. Work is cooled from temperature in still air

Annealing. For 0.60 to 0.90 C, heat to 1360 to 1400 °F (740 to 760 °C); for 0.90 to 1.50 C, heat to 1400 to 1450 °F (760 to 790 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies. Sections up to 1 in. (25 mm) require at least 20 min; 8-in. (203 mm) sections require 2½ hr. For pack annealing, hold for 1 hr per inch of cross section. Cool at a maximum rate of 50 °F (28 °C) per hour to 1000 °F (540 °C), after which controlled cooling is not necessary. Hardness after annealing, 156 to 201 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

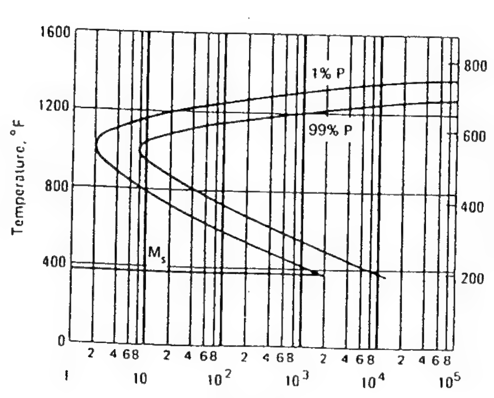
Hardening. Preheating is necessary only for intricate sections or large sections where temperatures would differ appreciably from surface to center. Heat slowly to 1400 to 1550 °F (760 to 845 °C), using the upper end of the temperature range for low carbon contents and lower end of the temperature range for high carbon contents. Using temperatures at the upper end of the temperature range will increase hardenability. Austenitize for 10 min for small sections to 30 min for large sections. Quench in agitated water or brine. A spray directed into a recessed configuration, such as a die cavity, or at the working end of a punch is often used to obtain maximum hardness and residual compressive stress in a desired area. Approximate quenched hardness, 65 to 68 HRC

Tempering. Temper immediately after hardening, preferably before tool reaches room temperature; about 120 °F (49 °C) is optimum. Allowing quenched tools to stand at room temperature or placing them in a cold furnace will lead to cracking. Therefore, place tools in a warm 200 to 250 °F (94 to 120 °C) furnace immediately after quenching and bring to tempering temperature with the furnace. Except for large pieces, work will heat at about the same rate as the furnace. Temper at temperatures not lower than 350 °F (175 °C) and up to about 650 °F (345 °C). One hour at temperature is usually adequate; additional soaking time will further lower hardness. A double temper may be required. The low temperatures used in tempering eliminate the need for atmosphere control. Approximate tempered hardness, 50 to 64 HRC

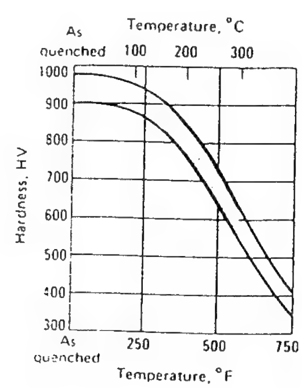
Recommended Processing Sequence

- Normalize
- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Temper (double temper, optional)
- Final grind to size

W1: Isothermal Transformation Diagram. (Source: British Iron and Steel Institute)



W1: Hardness Versus Tempering Temperature. (Source: British Steel)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: W2

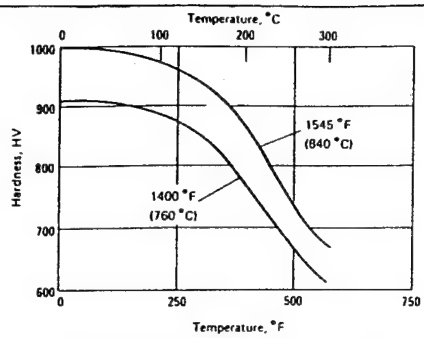
Water Hardening Tool Steel (W Series)

CHEMICAL COMPOSITION: AISI: Nominal. 0.60 to 1.40 C, 0.25 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	Necessary only for intricate shapes or large sections where surface to center temps. would differ significantly
2ND PREHEAT:	N/A
AUSTENITIZE:	1400 to 1550°F (10 mins. for small sections and 30 mins. for large sections) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Agitated Water or Brine
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour at temperature
2ND TEMPER:	May be required
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 65 to 68 - Use upper end of Austenitizing Temperature range for low carbon contents and lower end of range for high carbon contents - Temper immediately after quenching, preferably before reaching room temp. (120°F is optimum) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.



W2: Hardness Versus Tempering Temperature. Tempering band for W2 and W5, containing 0.90 to 1.10 C. Austenitized at 1400 °F (760 °C) and 1545 °F (840 °C). Shaded portion indicates optimum tempering range. (Source: British Steel)

W5

Chemical Composition. AISI: Nominal. 1.10 C, 0.50 Cr. **UNS:** 1.05 to 1.15 C, 0.40 to 0.60 Cr, 0.10 to 0.40 Mn, 0.030 P max, 0.030 S max, 0.10 to 0.40 Si

Similar Steels (U.S. and/or Foreign). UNS T72305; ASTM A686 (W-5)

Characteristics. Capable of hardening to high surface hardness and soft core which is useful in some shock applications. Low cost tool steels with fair to good wear resistance as carbon content increases. Water quenched with poor dimensional stability. Use limited to fairly uniform sections with minimum amount of stress raisers or quench cracking can occur

Forging. Start forging at 1800 to 1950 °F (980 to 1065 °C). Use upper temperatures for 0.60 to 1.25 C, and lower temperatures for 1.25 to 1.50 C. Do not forge below 1500 °F (815 °C)

Recommended Heat Treating Practice

Normalizing. For 0.60 to 0.75 C, heat to 1500 °F (815 °C); for 0.75 to 0.90 C, 1450 °F (790 °C); for 0.90 to 1.10 C, 1600 °F (870 °C); for 1.10 to 1.50 C, 1600 to 1700 °F (870 to 925 °C). After uniform through heating, holding time varies from about 15 min for small sections to about 1 hr for large sections. Work is cooled from temperature in still air

Annealing. For 0.60 to 0.90 C, heat to 1360 to 1400 °F (740 to 760 °C); for 0.90 to 1.50 C, heat to 1400 to 1450 °F (760 to 790 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies from at least 20 min for sections up to 1 in. (25 mm) to 2½ hr for sections of 8 in. (203 mm). For pack annealing, hold for 1 hr per inch of cross section. Cool at a maximum rate of 50 °F (28 °C) per hour to 1000 °F (540 °C), after which controlled cooling is not necessary. Hardness after annealing, 156 to 201 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Preheating is necessary only for intricate sections or large sections where temperatures would differ appreciably from surface to center. Heat slowly to 1400 to 1550 °F (760 to 845 °C), using the upper end of the temperature range for low carbon contents and lower end of the temperature range for high carbon contents. Using temperatures toward the upper end of the temperature range will increase hardenability. Austenitize 10 min for small sections to 30 min for large sections. Quench in agitated water or brine. A spray directed into a recessed configuration, such as a die cavity, or at the working end of a punch is often used to obtain maximum hardness and residual compressive stress in a desired area. Approximate quenched hardness is 65 to 68 HRC

Tempering. Temper immediately after hardening, preferably before tool reaches room temperature; about 120 °F (49 °C) is optimum. Allowing quenched tools to stand at room temperature or placing them in a cold furnace will lead to cracking. Therefore, place tools in a warm 200 to 250 °F (94 to 120 °C) furnace immediately after quenching and bring to tempering temperature with the furnace. Except for large pieces, work will heat at about the same rate as the furnace. Temper at temperatures not lower than 350 °F (175 °C) and up to about 650 °F (345 °C). One hour at temperature is usually adequate; additional soaking time will further lower hardness. A double temper may be required. The low temperatures used in tempering eliminate the need for atmosphere control. Approximate tempered hardness, 50 to 64 HRC

Recommended Processing Sequence

- Normalize
- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Temper (double temper, optional)
- Final grind to size

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

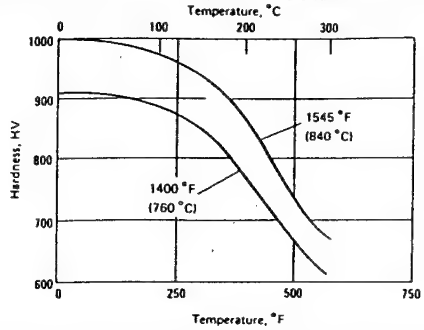
HEAT TREAT DATA SHEET

TYPE OF STEEL: **W5**
Water Hardening Tool Steel (W Series)
CHEMICAL COMPOSITION: AISI: Nominal. 1.10 C, 0.50 Cr

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	Necessary only for intricate shapes or large sections where surface to center temps. would differ significantly
2ND PREHEAT:	N/A
AUSTENITIZE:	1400 to 1550°F (10 mins. for small sections and 30 mins. for large sections) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Agitated Water or Brine
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 hour at temperature
2ND TEMPER:	May be required
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 65 to 68 - Use upper end of Austenitizing Temperature range for low carbon contents and lower end of range for high carbon contents - Temper immediately after quenching, preferably before reaching room temp. (120°F is optimum) - Atmosphere for Preheat &Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.



W2: Hardness Versus Tempering Temperature. Tempering band for W2 and W5, containing 0.90 to 1.10 C. Austenitized at 1400 °F (760 °C) and 1545 °F (840 °C). Shaded portion indicates optimum tempering range. (Source: British Steel)

W5

Chemical Composition. AISI: Nominal. 1.10 C, 0.50 Cr. **UNS:** 1.05 to 1.15 C, 0.40 to 0.60 Cr, 0.10 to 0.40 Mn, 0.030 P max, 0.030 S max, 0.10 to 0.40 Si

Similar Steels (U.S. and/or Foreign). UNS T72305; ASTM A686 (W-5)

Characteristics. Capable of hardening to high surface hardness and soft core which is useful in some shock applications. Low cost tool steels with fair to good wear resistance as carbon content increases. Water quenched with poor dimensional stability. Use limited to fairly uniform sections with minimum amount of stress raisers or quench cracking can occur

Forging. Start forging at 1800 to 1950 °F (980 to 1065 °C). Use upper temperatures for 0.60 to 1.25 C, and lower temperatures for 1.25 to 1.50 C. Do not forge below 1500 °F (815 °C)

Recommended Heat Treating Practice

Normalizing. For 0.60 to 0.75 C, heat to 1500 °F (815 °C); for 0.75 to 0.90 C, 1450 °F (790 °C); for 0.90 to 1.10 C, 1600 °F (870 °C); for 1.10 to 1.50 C, 1600 to 1700 °F (870 to 925 °C). After uniform through heating, holding time varies from about 15 min for small sections to about 1 hr for large sections. Work is cooled from temperature in still air

Annealing. For 0.60 to 0.90 C, heat to 1360 to 1400 °F (740 to 760 °C); for 0.90 to 1.50 C, heat to 1400 to 1450 °F (760 to 790 °C). Use lower limit for small sections and upper limit for large sections. Holding time varies from at least 20 min for sections up to 1 in. (25 mm) to 2½ hr for sections of 8 in. (203 mm). For pack annealing, hold for 1 hr per inch of cross section. Cool at a maximum rate of 50 °F (28 °C) per hour to 1000 °F (540 °C), after which controlled cooling is not necessary. Hardness after annealing, 156 to 201 HB

Stress Relieving. Optional. Heat to 1200 to 1250 °F (650 to 675 °C) and hold for 1 hr per inch of cross section (minimum of 1 hr). Cool in air

Hardening. Preheating is necessary only for intricate sections or large sections where temperatures would differ appreciably from surface to center. Heat slowly to 1400 to 1550 °F (760 to 845 °C), using the upper end of the temperature range for low carbon contents and lower end of the temperature range for high carbon contents. Using temperatures toward the upper end of the temperature range will increase hardenability. Austenitize 10 min for small sections to 30 min for large sections. Quench in agitated water or brine. A spray directed into a recessed configuration, such as a die cavity, or at the working end of a punch is often used to obtain maximum hardness and residual compressive stress in a desired area. Approximate quenched hardness is 65 to 68 HRC

Tempering. Temper immediately after hardening, preferably before tool reaches room temperature; about 120 °F (49 °C) is optimum. Allowing quenched tools to stand at room temperature or placing them in a cold furnace will lead to cracking. Therefore, place tools in a warm 200 to 250 °F (94 to 120 °C) furnace immediately after quenching and bring to tempering temperature with the furnace. Except for large pieces, work will heat at about the same rate as the furnace. Temper at temperatures not lower than 350 °F (175 °C) and up to about 650 °F (345 °C). One hour at temperature is usually adequate; additional soaking time will further lower hardness. A double temper may be required. The low temperatures used in tempering eliminate the need for atmosphere control. Approximate tempered hardness, 50 to 64 HRC

Recommended Processing Sequence

- Normalize
- Rough machine
- Stress relieve (optional)
- Finish machine
- Preheat
- Austenitize
- Quench
- Temper (double temper, optional)
- Final grind to size

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: 4130
Medium carbon alloy steel

CHEMICAL COMPOSITION: AISI: Nominal. 0.28 to 0.33 C, 0.40 to 0.60 Mn, 0.035 P max., 0.040 S max, 0.15 to 0.30 Si, 0.80 to 1.10 Cr, 0.15 to 0.25 Mo

PART PREPARATION/FIXTURING:

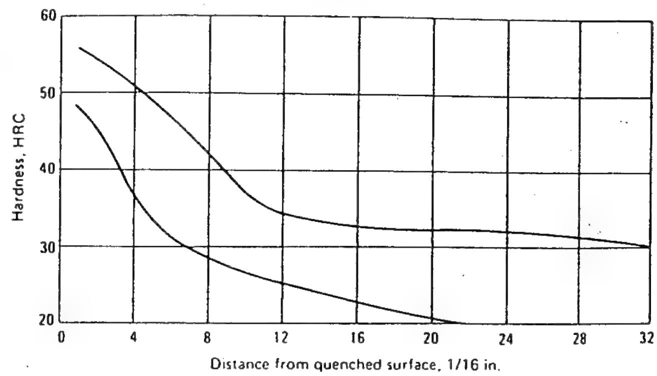
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1600°F (1 hour per inch of thickness) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil, or Polymer
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 51 to 56 - Atmosphere for Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

4130H: End-Quench Hardenability. (Source: *Metals Handbook*, 9th ed., Vol 1, American Society for Metals, 1978)

Distance from quenched surface 1/16 in.	Distance from quenched surface mm	Hardness, HRC max	Hardness, HRC min	Distance from quenched surface 1/16 in.	Distance from quenched surface mm	Hardness, HRC max	Hardness, HRC min
1	1.58	56	49	13	20.54	34	24
2	3.16	55	46	14	22.12	34	24
3	4.74	53	42	15	23.70	33	23
4	6.32	51	38	16	25.28	33	23
5	7.90	49	34	18	28.44	32	22
6	9.48	47	31	20	31.60	32	21
7	11.06	44	29	22	34.76	32	20
8	12.64	42	27	24	37.92	31	...
9	14.22	40	26	26	41.08	31	...
10	15.80	38	26	28	44.24	30	...
11	17.38	36	25	30	47.40	30	...
12	18.96	35	25	32	50.56	29	...

Source: *Metals Handbook*, 9th ed., Vol 1, American Society for Metals, 1978



4130: As-Quenched Hardness

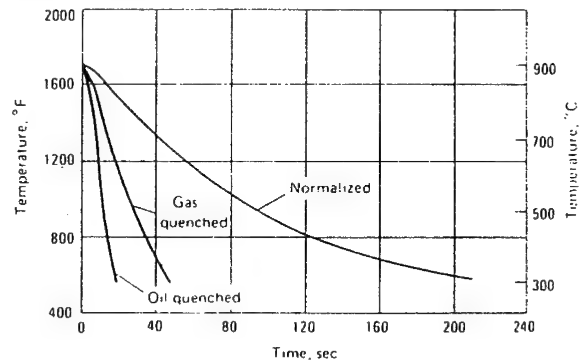
Specimens were quenched in water

Size round in.	Size round mm	Hardness, HRC Surface	Hardness, HRC ½ radius	Hardness, HRC Center
½	13	51	50	50
1	25	51	50	44
2	51	47	32	31
4	102	45.5	25	24.5

Source: Bethlehem Steel

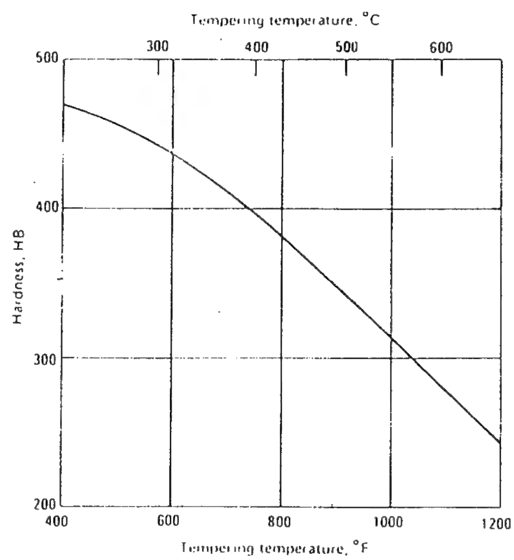
4130: Cooling Curves.

Steel tubing. 1.25-in. (31.75-mm) outside diameter by 0.065-in. (1.651-mm) wall. (Source: *Metals Handbook*, 8th ed., Vol 2, American Society for Metals, 1964)



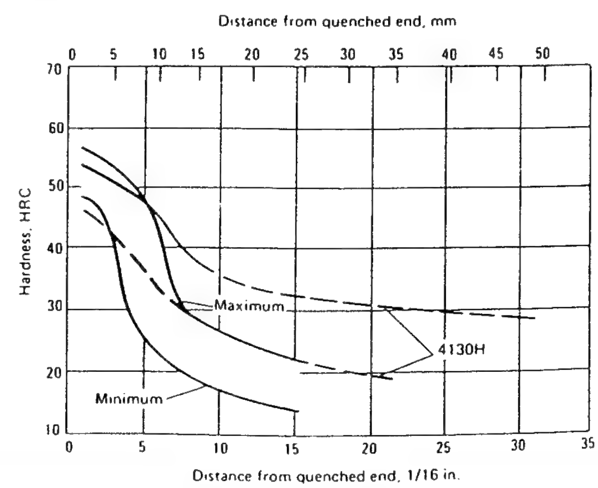
4130: Hardness Versus Tempering Temperature.

Normalized at 1650 °F (900 °C). Quenched from 1600 °F (870 °C) in water and tempered at 100 °F (56 °C) intervals in 0.540-in (13.7-mm) rounds. Tested in 0.505-in. (12.8-mm) rounds. (Source: Republic Steel)



4130H: End-Quench Hardenability.

48 heats of 14B35 containing 0.35 to 0.39 C, 0.65 to 1.10 Mn, 0.13 Ni max, 0.05 Cr max, 0.03 Mo max and boron treated; compared with 4130H. (Source: *The Hardenability of Steels*, American Society for Metals, 1977)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

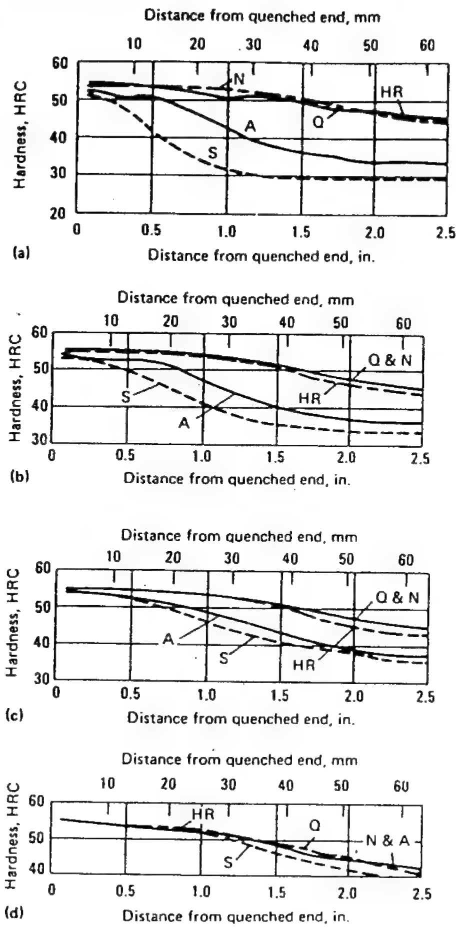
TYPE OF STEEL: 4340
High hardenability steel
CHEMICAL COMPOSITION: AISI: Nominal. 0.38 to 0.43 C, 0.60 to 0.80 Mn, 0.035 P max., 0.040 S max, 0.15 to 0.30 Si, 1.65 to 2.00 Ni, 0.70 to 0.90 Cr, 0.20 to 0.30 Mo

PART PREPARATION/FIXTURING:

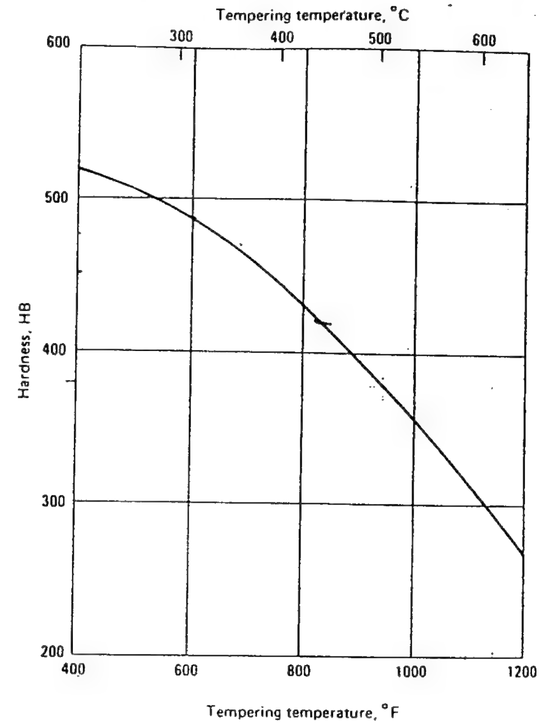
PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
1ST PREHEAT:	N/A
2ND PREHEAT:	N/A
AUSTENITIZE:	1550°F (1 hour per inch of thickness) note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil, or Polymer Fluidized Bed Quench Bath for thin sections
1ST TEMPER:	See "Hardness vs. Tempering Temperature" Curve 1 to 2 hours at temperature
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 50 to 55 - Temper immediately, after quench, when part has cooled to approx. 100 to 120°F - Atmosphere for Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

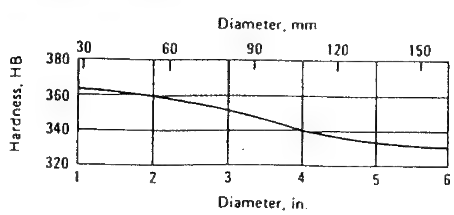
4340: End-Quench Hardenability. Influence of initial structure and time at 1550 °F (845 °C). HR: hot rolled, N: normalized, A: annealed, S: spheroidized. **(a)** 0 min; **(b)** 10 min; **(c)** 40 min; **(d)** 4 hr. (Source: *The Hardenability of Steels,* American Society for Metals, 1977)



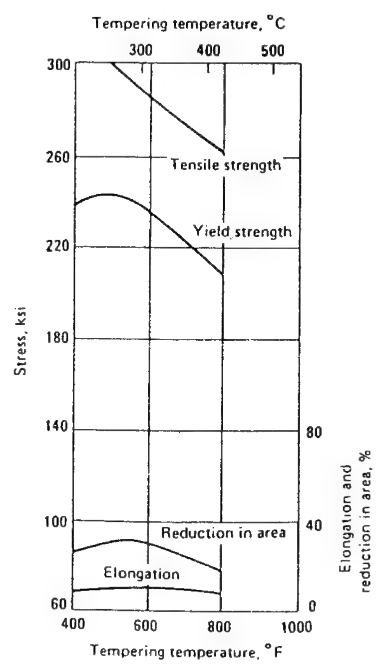
4340: Hardness Versus Tempering Temperature. Normalized at 1600 °F (870 °C), quenched from 1550 °F (845 °C), and tempered at 100 °F (56 °C) intervals in 0.540-in. (13.7-mm) rounds. Tested in 0.505-in. (12.8-mm) rounds. (Source: Republic Steel)



4340: Hardness Versus Diameter. 0.38 to 0.43 C, 0.60 to 0.80 Mn, 0.040 P max, 0.040 S max, 0.20 to 0.35 Si, 1.65 to 2.00 Ni, 0.70 to 0.90 Cr, 0.20 to 0.30 Mo. Approximate critical points: Ac_1, 1335 °F (725 °C); Ac_3, 1425 °F (775 °C); Ar_3, 1310 °F (710 °C); Ar_1, 1210 °F (655 °C). Forge at 2250 °F (1230 °C) maximum; anneal at 1100 to 1225 °F (595 to 660 °C) for a maximum hardness of 223 HB; normalize at 1550 to 1650 °F (845 to 900 °C) for an approximate hardness of 415 HB; quench in oil from 1525 to 1575 °F (830 to 855 °C). Test specimens normalized at 1600 °F (870 °C) in over-sized rounds, quenched from 1550 °F (845 °C) in oil, tempered at 1000 °F (540 °C). Tested in 0.505-in. (12.8-mm) rounds. Tests from 1½-in. (38-mm) diam bars and over are taken at half radius position. (Source: Republic Steel)



4340 + Si: Tensile Strength, Yield Strength Elongation, and Reduction in Area. Composition: 0.43 C, 0.83 Mn, 1.55 Si, 1.84 Ni, 0.91 Cr, 0.40 Mo, 0.12 V, 0.083 Al. Normalized at 1650 °F (900 °C), austenitized at 1575 °F (855 °C), quenched in agitated oil, tempered for 1 hr. (Source: Bethlehem Steel)



PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **17-4 PH**
Precipitation Hardening stainless Steel

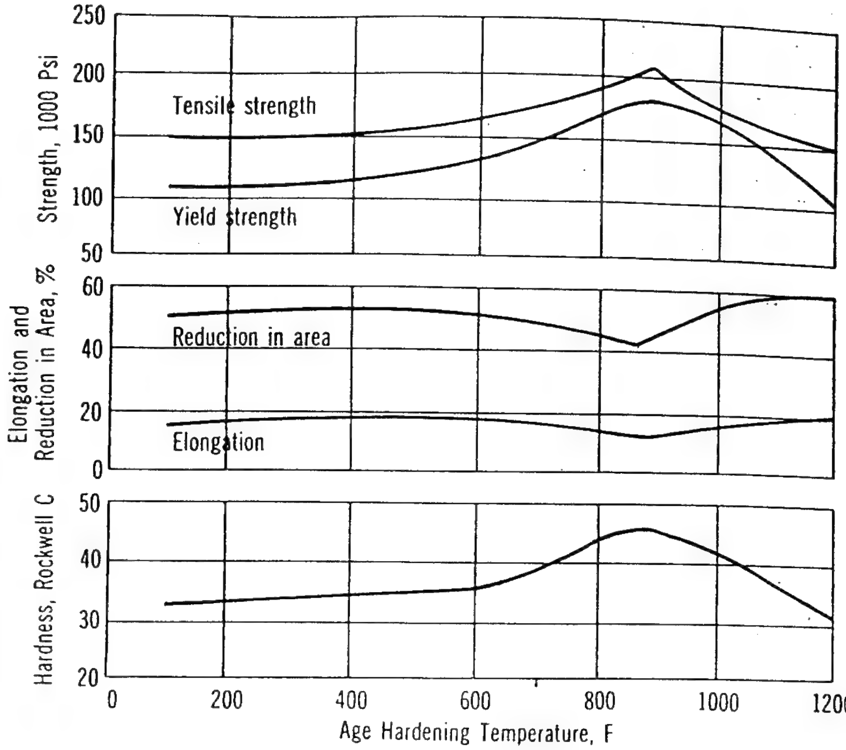
CHEMICAL COMPOSITION: AISI: Nominal. 0.07 C max., 1.0 Mn max., 1.0 Si max., 4.0 Ni max., 17.0 Cr max., 4.0 Cu max.

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Neutral Hardening
SOLUTION TREATMENT:	1900°F for 1 hour
TRANSFORMATION COOLING:	Fluidized bed Quench Bath or air cool to below +90°F
PRECIPITATION HARDENING (AGING):	Typically 900 to 1150°F for 4 hours See attached "Age Hardening Temp. vs. Hardness" Curve
STEP QUENCH:	N/A
QUENCH:	Fluidized Bed Quench Bath or Air Cool
1ST TEMPER:	N/A
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Atmosphere for solution treating, aging, and fluid bed quenching is 100% nitrogen

Age hardening at different temperatures alters the properties of 17-4 PH. Strengths peak in the 850 to 900 F range, then drop off.



to −100 F and held for 3 hr. Precipitation hardening develops minimum tensile strengths of 190,000 psi (850 F, 3 hr) and 170,000 psi (1000 F, 3 hr). For castings, a minimum tensile strength of 180,000 psi is reached by holding at a temperature of 850 F for 2 hr.

Equipment and Atmospheres

Thorough cleaning of parts before heat treatment pays dividends by facilitating scale removal. Taking off oils and lubricants (with solvents) also precludes carburization by them. When selecting heat treating equipment, consider heat source, atmosphere and control of temperature. Electric or gas-fired, radiant-tube furnaces are generally used, and air is satisfactory as an atmosphere for solution treating and annealing, except for precision forgings and investment castings. In fact, if temperatures are below 2000 F, most users recommend air since it will not alter surface compositions appreciably. In air, the castings scale moderately at 1900 F and heavily at 2000 F and higher.

Bright annealing may be done in a vacuum or hydrogen, argon or helium atmosphere if a dew point of −65 F or lower is maintained. The cooling rate must be approximately equal to that of cooling in still air. Solution treatments at 1700 to 1750 F may also be performed in a vacuum or dry hydrogen, argon or helium, producing a scalefree surface.

Because lower austenite-conditioning temperatures (such as 1400 F), present difficulties in obtaining scale-free surfaces in dry hydrogen, argon or helium, an air atmosphere is generally used. For complete freedom from scale or discoloration, a vacuum furnace is required. However, hardening is at relatively low temperatures, making an air atmosphere quite acceptable.

Users of precipitation hardening stainless steels, especially castings of 17-4 PH, often specify homogenizing above 1950 F before solution annealing and hardening. This treatment could be potentially harmful, and some heat treaters feel it is unnecessary. Above 2000 F, carbon and nitrogen can diffuse rapidly into these alloys. These elements tend to stabilize the austenite, reducing transformation below the degree required to assure effective hardening.

Also, many castings have been ruined by improperly controlled atmospheres which carburize or nitride the surface layers. Reducing atmospheres, such as dissociated ammonia or bright-annealing gas, introduce this hazard. Endothermic gas is usually not satisfactory because its minimum carburizing potential is 0.15 to 0.20%, and it can be as high as 0.35 to 0.40% at 1600 F.

Exothermic gas can be used if it is kept neutral by moisture. (If dry, it could carburize.) Also, this type of atmosphere can produce a tightly adherent scale generally calling for descaling in a strong solution such as sodium hydride.

Table I—Composition of Precipitation Hardening Stainless Steels

Grade*	C	Cr	Ni	Mo	Other
17-4 PH	0.03 max	11.0 to 13.0	7.0 to 10.0	—	1.0 to 3.0 Cu
17-7 PH	0.09 max	16.0 to 18.0	6.5 to 7.75	—	0.75 to 1.5 Al
15-7 Mo	0.09 max	14.0 to 16.0	6.5 to 7.75	2.0 to 3.0	—
14-8 Mo	0.02 to 0.05	13.5 to 15.5	7.5 to 9.5	2.0 to 3.0	0.75 to 1.5 Al
14-4 Mo	0.07 max	13.0 to 15.0	3.0 to 5.0	2.0 to 3.0	2.0 to 5.0 Cu
13-8 Mo	0.05 max	12.0 to 14.0	7.0 to 9.0	2.0 to 3.0	0.75 to 1.5 Al
AM-350	0.10 max	16.5 to 17.5	4.0 to 4.5	2.5 to 3.0	—
AM-355	0.10 to 0.15	15.0 to 16.0	4.0 to 5.0	2.5 to 3.25	—
AM-362	0.03 max	13.5 to 15.5	6.0 to 7.0	—	—
AM-363	0.05 max	11.0 to 12.0	4.0 to 5.0	—	—

*These alloys also contain small amounts of manganese, titanium, silicon, columbium, tantalum, boron, phosphorus, sulfur and nitrogen in various combinations.

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **Baldwin AH**
Medium Alloy, Air Hard. Cold Work Tool Steel (similar to A2)
CHEMICAL COMPOSITION: Not Available

PART PREPARATION/FIXTURING

PROCESS PARAMETERS

ANNEALING:	Pack at 1625°F and Furnace Cool
PROCESS:	Neutral Hardening
1ST PREHEAT:	1450°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1750 TO 1800°F (10 to 30 minutes) Note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil or Polymer
1ST TEMPER:	See attached chart. 1 to 2 hours at temperature.
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. as quenched hardness: HRC 62 to 65 - Atmosphere for Preheat & Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Temper immediately after quench, to prevent cracking (do not allow part to cool below 140°F) - Cool to room temp. after each temper.

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **Baldwin #1**
Oil Hardening Cold Work Tool Steel (similar to O-1)
CHEMICAL COMPOSITION: Not Available

PART PREPARATION/FIXTURING

PROCESS PARAMETERS

ANNEALING:	Heat slowly to 1375 to 1425°F
PROCESS:	Neutral Hardening
1ST PREHEAT:	1200°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1450 TO 1525°F (10 to 30 minutes) Note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil or Polymer
1ST TEMPER:	See attached chart. 1 to 2 hours at temperature.
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. as quenched hardness: HRC 63 to 65 - Atmosphere for Preheat & Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.

PICATINNY HEAT TREAT STUDY

NEUTRAL HARDENING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **Baldwin #711**
Shock Resisting Tool Steel (similar to S-7)
CHEMICAL COMPOSITION: Not Available

PART PREPARATION/FIXTURING

PROCESS PARAMETERS

ANNEALING:	Heat slowly to 1425 to 1475°F Cool slowly to 1000°F
PROCESS:	Neutral Hardening
1ST PREHEAT:	1200 to 1300°F
2ND PREHEAT:	N/A
AUSTENITIZE:	1625°F (10 to 30 minutes), 1550 for Water Quench. Note: time at temp.
STEP QUENCH:	N/A
QUENCH:	Oil, Polymer, or Water.
1ST TEMPER:	See attached chart. 1 to 2 hours at temperature.
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. as quenched hardness: HRC 60 to 61 - Atmosphere for Preheat & Austenitizing: 100% Nitrogen - Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition. - Temper immediately after parts reach room temp.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 410

ANNEALING:

Subcritical Anneal: 1200 - 1400. Time at temperature per MIL-H-6875 Table IIA. Air cool

Isothermal Anneal: 1525 to 1625. Slowly cool to 1300, and hold for 6 hours. Approximate hardness: 85 HrB.

Full Anneal: 1525 to 1625. Cooling rate 40°/hr max to 1100. After this, cooling rate is no longer critical. Hardness: 75 to 85 HrB.

HARDEN AND TEMPER:

Harden: Preheat 1400 to 1450 long enough to equalize.
Then 1700 to 1850. Time at temperature per HIL-H-6875 Table IIA.
When tempering temperature is to exceed 1050, use low side of hardening temperature range.

Quench: Oil, polymer, or air. Use oil or polymer to get optimum corrosion resistance.
Marquenching is acceptable.

Temper: 400 to 700 for HRc 38 to 47
1025 to 1125 for HRc 25 to 31
Double temper, allow to cool to room temperature between tempers.

Stabilization: -105 to -320. Temper immediately after.

Nitriding: Depassivate before nitriding.
Nitride 48 hours at 975 to 1025. Temperature should be at least 25° below tempering temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 414

ANNEALING:

For best machinability, heat to 1750, and air cool. Temper for 1200 to 1350. HRb 99 to HRc 24.

For subsequent hardening, 1200 to 1350 temper is sufficient.

For improved machinability prior to subsequent hardening, heat to 1500 to 1550, air cool, and temper at 1150 to 1300.

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 long enough only to equalize temperature. 1700 - 1925. Time at temperature per MIL-H-6875, Table IIA
Quench:	Quench in oil, polymer, or air. Use oil or polymer to get optimum corrosion resistance. Marquenching is permissible.
Temper:	450 to 700 for HRc 45 1100 to 1200 for HRc 25 to 31 Double temper cooling to room temperature between tempers.
Stabilization:	-105 to -320. Temper immediately after.
Nitriding:	Depassivate before nitriding. Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 416, 416 Se

ANNEALING:

Process Anneal:	1200 to 1400 for HRb 86 to 92. Air cool.
Isothermal Anneal:	1525 to 1625. Slow Cool to 1325 and hold for 2 hours. Approx. HRb 85.
Full Anneal:	1525 to 1625. Cool at 40°/hr Max. to 1100. HRb 75 to 85.

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 just enough to equalize temperature. 1700 to 1850. Time at temperature per MIL-H-6875 Table IIA.
Quench:	Oil or Polymer Quench. Marquenching is permissible.
Temper:	400 to 700 for HRc 35 to 45 1050 to 1125 for HRc 25 to 31 Double temper cooling to room temperature between tempers.
Stabilization:	-105 to -320. Temper immediately after.

Nitriding:	Depassivate before nitriding. Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 420, 420F

ANNEALING:

Process Anneal:	1250 to 1400. Air Cool. HRb 94 to 97
Isothermal Anneal:	1525 to 1625. Cool slowly to 1300 and hold 2 hours. Approx. HRb 95.
Full Anneal:	1525 to 1625. Cool at 40°/hr Max to 1100. HRb 86 to 95.

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 long enough to equilize parts. 1800 to 1950. Time at Temperature per MIL-H-6875 Table IIA.
Quench:	Oil or Polymer Marquenching is acceptable.
Temper:	400 to 700 for HRc 48 to 56. Double temper, cooling to room temperature between tempers.
Stabilization:	-105 to -320. Temper immediately after stabilizing.

Nitriding:	Depassivate before nitriding. Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 422

ANNEALING:

Process Anneal only: 1350 to 1450. Air cool.

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 long enough to equilize parts. 1900 for 1 hour.
Quench:	Air or Water then immediately go into cold stabilization
Temper:	1200 for 2 hours. Approximately 320 BHN
Stabilization:	-100 ± 20.

Nitriding:	Depassivate before nitriding. Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 431

ANNEALING:

Process Anneal Only: 1150 to 1300, 6 hours minimum. Air cool.

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 long enough to equilize parts. 1800 to 1950. Time at temperature per MIL-H-6875 Table IIA.
Quench:	Air, Oil, or Polymer. Oil or polymer preferred in order to obtain maximum corrosion resistance. Marquenching is acceptable.
Temper:	450 to 700 for HRc 40 to 47 1050 to 1125 for HRc 26 to 34 Double temper. Cool to room temperature between tempers.
Stabilization:	-100 ± 20.
Nitriding:	Depassivate before nitriding. Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 440A

ANNEALING:

Process Anneal:	1250 to 1400. Air cool. HRb 90 to HRc 22
Isothermal Anneal:	1550 to 1650. Cool slowly to 1275 and hold for 4 hours. Approx. HRb 98.
Full Anneal:	1550 to 1650. Cool at 40°/hr max to 1100. HRb 94 to 98

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 long enough to equilize parts. 1850 to 1950. Time at temperature per MIL-H-6875 Table IIA.
Quench:	Oil, Air, or Polymer. Oil or polymer is preferred to develop maximum corrosion resistance. Marquenching is acceptable.
Temper:	300 to 700. HRc 48 to 57. Double temper. Cool to room temperature between tempers.
Stabilization:	-100 ± 20.

Nitriding: Depassivate before nitriding.
Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 440B

ANNEALING:

Process Anneal:	1250 to 1400. Air Cool. HRb 98 to HRc 23.
Isothermal Anneal:	1550 to 1650. Cool slowly to 1250. Hold for 4 hours. Approx. HRc20.
Full Anneal:	1550 to 1650. Cool at 40°/hr Max to 1100. HRb 94 to 98

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 long enough to stabilize parts. 1850 to 1950. Time at temperature per MIL-H-6875 Table IIA.
Quench:	Air, Oil, or Polymer. Oil or polymer preferred to develop maximum corrosion resistance. Martempering is acceptable.
Temper:	300 to 700. HRc 53 to 59. Double temper. Cool to room temperature between tempers.
Stabilization:	-100 ± 20

Nitriding: Depassivate before nitriding.
Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

MARTENSITIC STAINLESS STEEL
HEAT TREATING CYCLES
MATERIAL: 440C

ANNEALING:

Process Anneal:	1250 to 1400. Air Cool. HRb 98 to HRc 23.
Isothermal Anneal:	1550 to 1650. Cool slowly to 1275 and hold 4 hours. Approx. HRc 25.
Full Anneal:	1550 to 1650. Cool 40°/hr Max. to 1100. HRb 98 to HRc 25.

HARDEN AND TEMPER:

Harden:	Preheat 1400 to 1450 long enough to stabilize parts. 1850 to 1950. Time at temperature per MIL-H-6875 Table IIA.
Quench:	Air, Oil, or Polymer. Use oil or polymer to develop maximum corrosion resistance. Marquenching is acceptable.
Temper:	325 for HRc 60 375 for HRc 58 450 for HRc 57 675 for HRc 52 to 56. Double temper. Cool to room temperature between tempers.
Stabilization:	-100 ± 20.

Nitriding: Depassivate before nitriding.
Nitride 48 hours between 975 and 1025. Temperature should be at least 25° below temper temperature.

TABLE 1: SUGGESTED HEAT UP TIMES FOR FLUIDIZED BED HEAT TREATING OF CLASS A & B STEELS (AS DEFINED IN MIL-H-6875)

Thickness (in)	Minimum Time (minutes)
≤ 0.250	15
0.251 - 0.500	20
0.501 - 1.000	30
1.001 - 1.500	40
1.501 - 2.000	50
2.001 - 2.500	60
2.501 - 3.000	70
3.001 - 3.500	80
3.501 - 4.000	90
4.001 - 5.000	110
5.001 - 6.000	130
6.001 - 7.000	150
7.001 - 8.000	170
Each Additional Inch + Fraction Thereof	10 minutes

Appendix A

TABLE 2:
HEAT TREATMENTS FOR
AUSTENITIC STAINLESS STEELS

MATERIAL	ANNEAL[A]	STRESS RELIEVE[B]	NITRIDE[C]
201	1850 - 2050	450 - 750	975 - 1025
202	1850 - 2050	450 - 750	975 - 1025
205	1950	450 - 750	975 - 1025
301	1850 - 2050	450 - 750	975 - 1025
302 & 302B	1850 - 2050	450 - 750	975 - 1025
303 & 303Se	1850 - 2050	450 - 750	975 - 1025
304. 304L, & 304N	1850 - 2050	450 - 750	975 - 1025
305	1850 - 2050	450 - 750	975 - 1025
308	1850 - 2050	450 - 750	975 - 1025
309 & 309S	1900 - 2050	450 - 750	975 - 1025
310 & 310S	1900 - 2100	450 - 750	975 - 1025
314	2100	450 - 750	975 - 1025
316, 316L[D], & 316N	1850 - 2050	450 - 750/1250 for L gr.	975 - 1025
316F	2000	450 - 750	975 - 1025
317	1850 - 2050	450 - 750	975 - 1025
317L[D]	1900 - 2000	1250	975 - 1025
321[D]	1750 - 2050	1300	975 - 1025
329	1750 - 1800	450 - 750	975 - 1025
330	1950 - 2150	450 - 750	975 - 1025
347	1850 - 2050	450 - 750	975 - 1025
348	1850 - 2050	450 - 750	975 - 1025
384	1900 - 2100	450 - 750	975 - 1025

A. For heating times and cooling method, refer to MIL-H-6875 Table IIB.

B. Hold for up to several hours, depending on size. Verify structure metallographically before and after to ensure no change from stress relief.

C. Nitride 20 to 48 hours, depending on required case. Remove oxide film prior to nitriding. Perform only when parts are required to be non magnetic or need wear resistant surface.

D. Stabilization required in 316L and 317L because of Mo. Hold at 1625 for 2 hours before stress relieving at 1250. For 321, stabilize anneal at 1550 to 1650 for up to 5 hours, depending on cross section, and then stress relieve at 1300 for short time.

TABLE 3:
HEAT TREATMENTS FOR
FERRITIC STAINLESS STEELS

MATERIAL	ANNEAL[A]	NITRIDE
405	1350 - 1500	Same as Austenitic
409	1600 - 1650	Same as Austenitic
429	1450 - 1550	Same as Austenitic
430	1400 - 1500	Same as Austenitic
430 F & FSe	1250 - 1400	Same as Austenitic
434	1450 - 1550	Same as Austenitic
436	1450 - 1550	Same as Austenitic
442	1350 - 1500	Same as Austenitic
446	1450 - 1600	Same as Austenitic

A. Anneal for 1 to 2 hours, except for sheet which should be soaked for 3 to 5 minutes per 0.10 "

Appendix B:

Process Flow Diagrams for Case Hardening

Process Flow for Carburizing Processes

Traditional Carburizing

Carburize

Slow Cool

Harden & Temper Test Piece

Harden, Quench, & Temper

Total Furnaces & Operations = 5
Includes Test Sample Heat Treating

Fluidized Bed Carburizing

Carburize

Lower Temp. & Direct Quench

Temper

Total Furnaces & Operations = 2

Note: Carbonitride will have the same process, except carbonitride will be done anywhere carburizing is indicated.

Process Flow for Nitriding Processes

Traditional Nitriding

Temper

|

Air Cool

|

Nitride

Total Furnaces & Operations = 2
Includes Test Sample Heat Treating

Fluidized Bed Nitriding

Temper

|

Cool Furnace

|

Nitride

Total Furnaces & Operations = 1

Note: Nitrocarburize will have the same process, except nitrocarburize will be done anywhere nitriding is indicated.

Appendix C: Theoretical Basis for Carburization

CASE 1: No Surface Condition Requirements -- Depth Only

Procedure:

1. Determine carbon concentration of the base metal (Cb).
2. Determine or estimate carbon potential in furnace (from experience or setpoint)(Cp).
3. Determine the carbon content at the case border (Cc).
4. Calculate the time required to achieve the desired case depth from the following formula.

$$\frac{(Cc - Cb)}{(Cp - Cb)} = \operatorname{erfc} \frac{(x)}{2\sqrt{Dt}} \quad \text{and calculate for t}$$

where: x = desired case depth in mm

D = diffusion coefficient of carbon in austenite in mm^2/sec. Typical values for D can be found in the gas carburization

t = time in seconds.

erfc(x) = 1 - erf (x). Values for erf can be found in mathmatical books such as the Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables published by the U.S. Department of Commerce, National Bureau of Standards.

Case 2:

Surface Requirements will dictate an approximate surface content of between .78 and .82 (minimize carbide distribution and retained austenite).

In this case, there are two options: the first is to control the carbon potential of the furnace at .8%. This is not the desired route in a fluidized bed furnace, because the whole cycle will have to be run with carburizing gases. In this case the process is governed by the same equation as Case 1, using a carbon potential of .8.

The second option is to run a boost - diffuse cycle. This process entails running for a short period of time with carburizing gases at a very high potential. The surface carbon will be very high, and yield a very undesirable structure without further processing. The further processing entails a diffusion cycle under a protective non-carburizing atmosphere. This cycle will cause diffusion of carbon into the steel, deepening the case, and lowering the surface carbon. A boost time will have to be selected (a starting guideline is approximately 1/4 to 1/3 of the normal carburizing time).
Each segment of the process is governed by different equations, and the key to modelling is to treat the carbon placed into the steel as a charge for a fixed source diffusion process. The following procedure and equations are used.

1. First, determine the time of the boost cycle. Use the same equation as Case 1 to determine the case depth build up during this time (solve for x).

2. Convert conditions from infinite source diffusion to fixed source diffusion using the following equation, to solve for t (adjusted time):

$$Cn = Co \exp \frac{(-x2)}{(4Dt)}$$

Where: $Cn = Cc - Cb$ x = case depth from step 1

$Co = Cp - Cb$ D = diffusion of carbon in austenite

3. Determine charge Q using the following equation:
   $Q = Co\sqrt{(\pi Dt)}$ solving for Q.
4. Estimate a diffusion time and determine both case depth and surface concentration as follows:
   * First determine the total process time t* as diffusion time + t from step 2.
   * Determine surface concentration using the following formula.
     $Co^* = Q/\sqrt{(\pi Dt^*)}$ and $Csurf = Co^* + Cb$
   * Determine case depth using the following formula:
     $Cn = (Co^*) [\exp(-x2/4Dt^*)]$ and solve for x.

To get the exact cycle may require several iterations. Software programs to conduct such analyses are available.

Appendix D:

Case Depth Experience

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET

TYPE OF STEEL: **H10**
Hot Work Tool Steel (H Series)

CHEMICAL COMPOSITION: AISI: Nominal. 0.40 C, 2.50 Mo, 3.25 Cr, 0.40 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:
PROCESS: <u>**CARBURIZING**</u>

CYCLE TIME:	6 HOURS FOR EFFECTIVE CASE DEPTH OF 0.060"
CYCLE TEMPERATURE:	1700°F
ATMOSPHERE:	
NITROGEN:	37%
NAT. GAS:	3%
METHANOL:	60%
AMMONIA:	0%
DIFFUSION CYCLE:	FURNACE COOL TO 1550°F, UNDER 100% NITROGEN
QUENCH:	FLUIDIZED BED QUENCH BATH OPERATING ON NITROGEN
HARDENING:	
1ST PREHEAT:	1020°F, UNDER 100% NITROGEN
2ND PREHEAT:	1550°F, UNDER 100% NITROGEN
AUSTENITIZE:	1880°F, UNDER 100% NITROGEN

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET (CONTINUED)

STEP QUENCH:	1020°F, UNDER 100% NITROGEN (ALLOW LOAD TO EQUILIBRATE)
QUENCH:	FLUIDIZED BED QUENCH BATH OPERATING ON NITROGEN
1ST TEMPER:	2 HOURS AT 1020°F, UNDER 100% NITROGEN
2ND TEMPER:	2 HOURS AT 1110°F, UNDER 100% NITROGEN
3RD TEMPER:	2 HOURS AT 1020°F, UNDER 100% NITROGEN

NOTE: COOL TO ROOM TEMP. IN A FLUIDIZED BED QUENCH BATH AFTER EACH TEMPER

COMMENTS:

-HARDENING TIMES ARE DEPENDENT ON SIZE OF PARTS.
-SURFACE HARDNESS: (AFTER TEMPERING) HRC 57 TO 59
-CORE HARDNESS: HRC 50
-TEMPER IMMEDIATELY, AFTER QUENCH, WHEN LOAD HAS COOLED TO APPROX. 125°F

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET

TYPE OF STEEL: H13
Hot Work Tool Steel (H Series)

CHEMICAL COMPOSITION: AISI: Nominal. 0.35 C 1.50 Mo, 5.00 Cr, 1.00 V

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS: NITRIDING

CYCLE TIME: **

CYCLE TEMPERATURE: 1000°F

ATMOSPHERE:

NITROGEN:	60%
NAT. GAS:	0%
METHANOL:	0%
AMMONIA:	40%

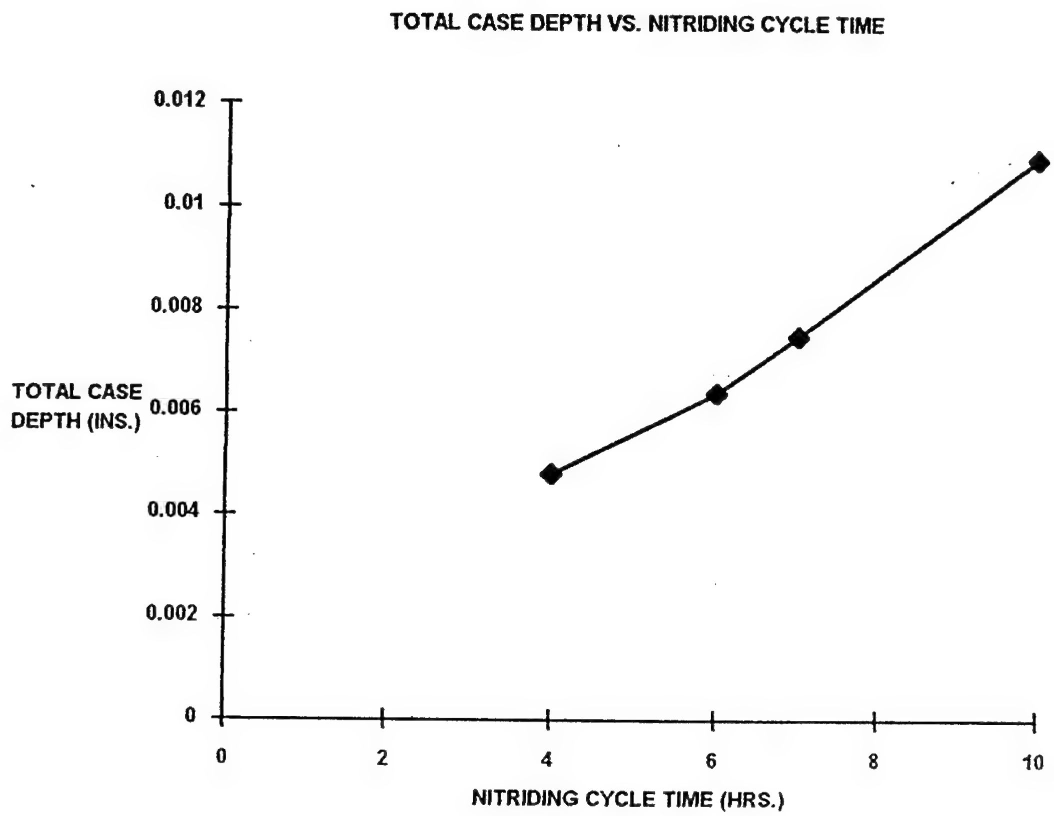
DIFFUSION CYCLE: Diffuse 1 Hour under 100% Nitrogen for every 4 Hours of Nitriding (At Nitriding Temperature)

QUENCH: FLUIDIZED BED QUENCH BATH OR AIR COOL

NO TEMPERING REQUIRED

COMMENTS: ** TOTAL CASE DEPTH VS. NITRIDING CYCLE TIME CURVE ATTACHED
GENERAL GUIDELINE: CASE DEPTH FORMS AT THE RATE OF APPROX. 0.001" PER HOUR FOR THE FIRST 24 HOURS.
SURFACE HARDNESS: (APPROX.) 15N 92 TO 92.5 (EQUIV. HRC 64 TO 66)
LOW FLOW GAS SAVER IS USED FOR LONG CYCLE NITRIDING (TYPICALLY 10 TO 20% OF FULL FLOW)

H13


TOTAL CASE DEPTH VS. NITRIDING CYCLE TIME
TOTAL CASE DEPTH (INS.)
0.012
0.01
0.008
0.006
0.004
0.002
0
0
2
4
6
8
10
NITRIDING CYCLE TIME (HRS.)

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET

TYPE OF STEEL: **P6**
Mold Steel (P Series)

CHEMICAL COMPOSITION: AISI: Nominal. 0.10 C, 1.50 Cr, 3.50 Ni

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:
PROCESS: **CARBURIZING**

CYCLE TIME:	40 Minutes for Effective Case Depth of 0.009"
CYCLE TEMPERATURE:	1650°F
ATMOSPHERE:	
NITROGEN:	37%
NAT. GAS:	3%
METHANOL:	60%
AMMONIA:	0%
DIFFUSION CYCLE:	Furnace cool to 1500°F, under 100% Nitrogen
QUENCH:	Agitated oil,or polymer (large sections) Fluidized Bed Quench Bath (small sections)
1ST TEMPER:	2 Hours at 375°F

COMMENTS:
-Surface Hardness: (After Tempering) HR15N 88.5 T0 89.5
-Core Hardness: Equiv. HRC 31.5
-Atmosphere for Tempering: Air or Nitrogen depending on temperature and desired surface condition.
-Effective case depth measured to HRC 50

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET

TYPE OF STEEL: **4340**
High hardenability steel

CHEMICAL COMPOSITION: AISI: Nominal. 0.38 to 0.43 C, 0.60 to 0.80 Mn, 0.035 P max., 0.040 S max, 0.15 to 0.30 Si, 1.65 to 2.00 Ni, 0.70 to 0.90 Cr, 0.20 to 0.30 Mo

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS: **NITRIDING**

CYCLE TIME: **

CYCLE TEMPERATURE: 1000°F

ATMOSPHERE:

NITROGEN:	60%
NAT. GAS:	0%
METHANOL:	0%
AMMONIA:	40%

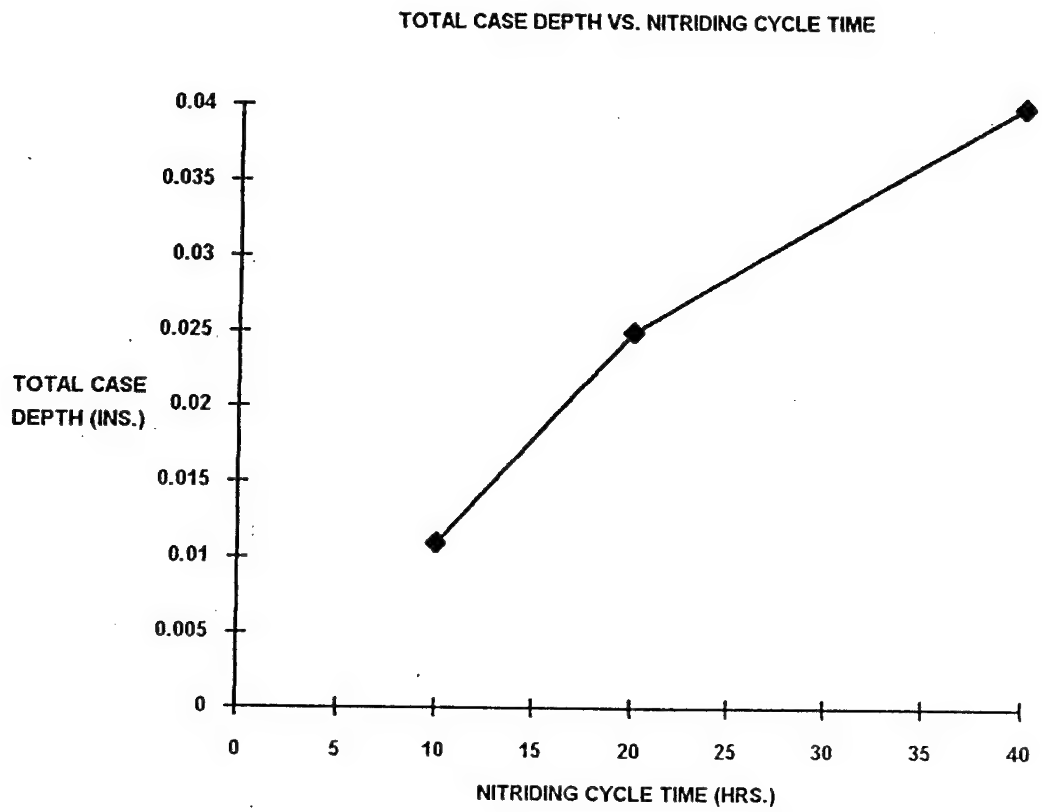
DIFFUSION CYCLE: Diffuse 2 Hours under 100% Nitrogen for every 10 Hours of Nitriding (At Nitriding Temperature)

QUENCH: FLUIDIZED BED QUENCH BATH OR AIR COOL

NO TEMPERING REQUIRED

COMMENTS: ** TOTAL CASE DEPTH VS. NITRIDING CYCLE TIME CURVE ATTACHED
GENERAL GUIDELINE: CASE DEPTH FORMS AT THE RATE OF APPROX. 0.001" PER HOUR FOR THE FIRST 24 HOURS.
LOW FLOW GAS SAVER IS USED FOR LONG CYCLE NITRIDING (TYPICALLY 10 TO 20% OF FULL FLOW)

4340


TOTAL CASE DEPTH VS. NITRIDING CYCLE TIME
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
TOTAL CASE DEPTH (INS.)
0
5
10
15
20
25
30
35
40
NITRIDING CYCLE TIME (HRS.)

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET

TYPE OF STEEL: 4340
High hardenability steel

CHEMICAL COMPOSITION: AISI: Nominal. 0.38 to 0.43 C, 0.60 to 0.80 Mn, 0.035 P max., 0.040 S max, 0.15 to 0.30 Si, 1.65 to 2.00 Ni, 0.70 to 0.90 Cr, 0.20 to 0.30 Mo

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS: NITROCARBURIZING

CYCLE TIME: 3 Hours for Compound Zone Depth of 0.0004" with Total Case Depth of 0.016".

CYCLE TEMPERATURE: 1060°F

ATMOSPHERE:

NITROGEN:	8%
NAT. GAS:	52%
METHANOL:	0%
AMMONIA:	40%

DIFFUSION CYCLE: N/A

QUENCH: Fluidized Bed Quench Bath operating on Nitrogen or Air Cool

1ST TEMPER: N/A

COMMENTS:

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET

TYPE OF STEEL: 4340
High hardenability steel

CHEMICAL COMPOSITION: AISI: Nominal. 0.38 to 0.43 C, 0.60 to 0.80 Mn, 0.035 P max., 0.040 S max, 0.15 to 0.30 Si, 1.65 to 2.00 Ni, 0.70 to 0.90 Cr, 0.20 to 0.30 Mo

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS: <u>CARBURIZING</u>

CYCLE TIME: 4 Hours for Effective Case Depth of 0.032"

CYCLE TEMPERATURE: 1700°F

ATMOSPHERE:

NITROGEN:	37%
NAT. GAS:	3%
METHANOL:	60%
AMMONIA:	0%

DIFFUSION CYCLE: Furnace cool to 1550°F, under 100% Nitrogen

QUENCH: Agitated oil,or polymer
(ie.: 12% Tenaxol "E" @ 110°F)

1ST TEMPER: 2 Hours at 600°F

COMMENTS:
-Surface Hardness: (After Tempering) HRC 54
-Core Hardness: Equiv. HRC 48
-Atmosphere for Tempering: 100% Nitrogen
-Effective case depth measured to HRC 50

PICATINNY HEAT TREAT STUDY

AUSTEMPERING

HEAT TREAT DATA SHEET

TYPE OF STEEL: **4340**
High hardenability steel

CHEMICAL COMPOSITION: AISI: Nominal. 0.38 to 0.43 C, 0.60 to 0.80 Mn, 0.035 P max., 0.040 S max, 0.15 to 0.30 Si, 1.65 to 2.00 Ni, 0.70 to 0.90 Cr, 0.20 to 0.30 Mo

PART PREPARATION/FIXTURING:

PROCESS PARAMETERS:

PROCESS:	Austempering
1ST PREHEAT:	30 Minutes at 1200°F, under 100% Nitrogen
2ND PREHEAT:	N/A
AUSTENITIZE:	40 Minutes at 1550°F, under 100% Nitrogen note: time at temp.
STEP QUENCH:	N/A
DYNAQUENCH:	40 Minutes at 640°F, 2 Minutes under 100% Helium - Balance under 100% Nitrogen
1ST TEMPER:	N/A
2ND TEMPER:	N/A
3RD TEMPER:	N/A
COMMENTS:	- Approx. As Quenched Hardness: HRC 42 to 43 - Cool to Room Temp. in aFluidized Bed Quench Bath, operating on Nitrogen, after Dynaquench

PICATINNY HEAT TREAT STUDY

ATMOSPHERE HEAT TREAT

DATA SHEET

TYPE OF STEEL: **17-4 PH**
Precipitation Hardening stainless Steel

CHEMICAL COMPOSITION: AISI: Nominal. 0.07 C max., 1.0 Mn max., 1.0 Si max., 4.0 Ni max., 17.0 Cr max., 4.0 Cu max.

PART PREPARATION/FIXTURING: Surface Prep.: Degrease and Grit Blast

PROCESS PARAMETERS:

PROCESS: **NITRIDING**

CYCLE TIME: **

CYCLE TEMPERATURE: 1075°F

ATMOSPHERE:

NITROGEN:	60%
NAT. GAS:	0%
METHANOL:	0%
AMMONIA:	40%

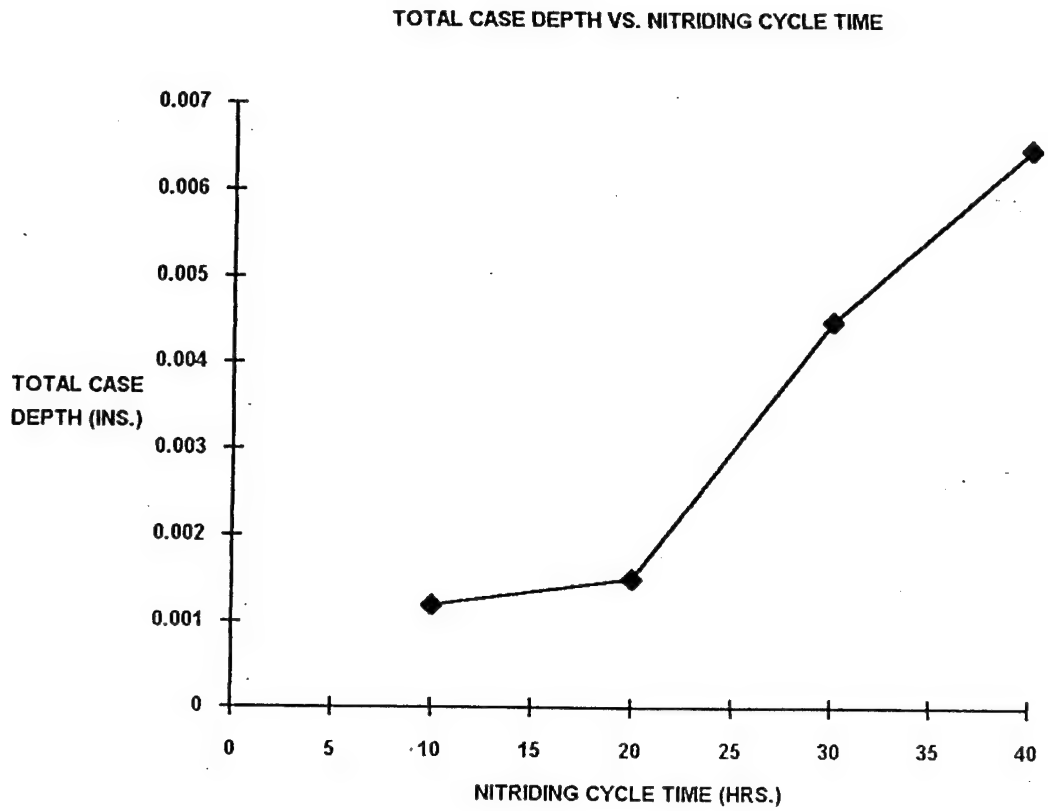
DIFFUSION CYCLE: Diffuse 2 Hours, under 100% Nitrogen, for every 10 Hours of Nitriding (At Nitriding Temperature)

QUENCH: Fluidized Bed Quench Bath or Air Cool

NO TEMPERING REQUIRED

COMMENTS: ** Total Case Depth vs. Nitriding Cycle Time Curve Attached
Surface Hardness: (approx.) R15N 92.5 to 95 (equiv. HRC 66 TO 70)
Low Flow Gas Saver is used for Long Cycle Nitriding
(Typically 10 TO 20% of Full Flow)

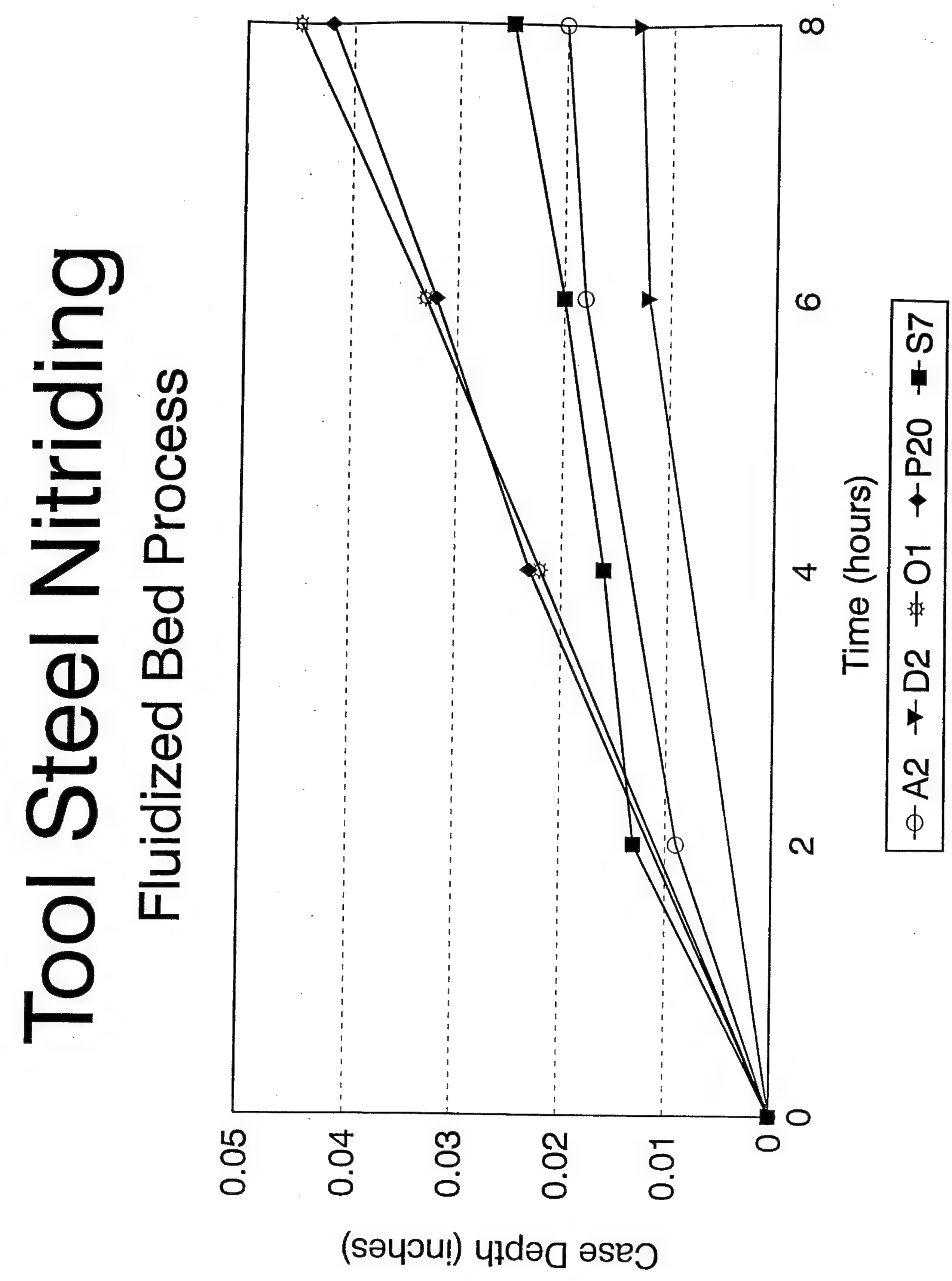
17-4PH
STAINLESS STEEL



SUMMARY OF PROCEDYNE SURFACE HEAT TREATMENT EXPERIENCE

Alloy	Process	Temp.	Time	Case	Atmosphere	Source	Comments
4125	Carburize	1775	4	0.102		Fukuda et. al	Carbon Potential = 2.3%
4340	Carburize	1700	4	0.032			
H10	Carburize	1700	6	0.06		Procedyne Lab	
P6	Carburize	1650	0.67	0.009		Procedyne Lab	
17-4	Nitride	1050	6	0.0023		Japka/Procedyne	
410 SS	Nitride	1020	6	0.032		Procedyne Lab	Passivate first
410 SS	Nitride	1050	3	0.0022		Japka/Procedyne	
4142	Nitride	980	14	0.02	60N2/40NH3	Procedyne Lab	2 hr. diffuse
D2	Nitride	985	8	0.004		Fukuda et. al	
H10	Nitride	1020	8	0.0065		Procedyne Lab	
H13	Nitride	985	8	0.01		Fukuda et. al.	
H13	Nitride	1000	7	0.008	60N2/40NH3	Procedyne Lab	Plus 2 hr diffuse
M2	Nitride	985	8	0.006		Fukuda et. al.	
M52	Nitride	980	0.33	0.0008	60N2/40NH3	Procedyne Lab	Follow with black oxiding
P-20*	Nitride	1000	18	0.0076	60N2/40NH3	Procedyne Lab	Low Flow + 4hr Diffuse
316SS	Nitrocarburize	1050	6	0.0031		Japka/Procedyne	
410SS	Nitrocarburize	1050	1.5	0.0015		Japka/Procedyne	
4140	Nitrocarburize	950	7	0.013	52CH4/40NH3/8N2	Procedyne Lab	inc. 1 hr diffuse
4140	Nitrocarburize	1060	3	0.016	40NH3/60CH4	Procedyne Lab	Preheat 800 for 15 minutes
4140	Nitrocarburize	1060	1	0.024		Procedyne Lab	Steam Blackening After
4340	Nitrocarburize	1060	3	0.016		Procedyne Lab	
M2	Nitrocarburize	975	0.33	0.0006	40NH3/60CH4	Procedyne Lab	
P20	Nitrocarburize	1050	5	.005 - .007		Procedyne Lab	

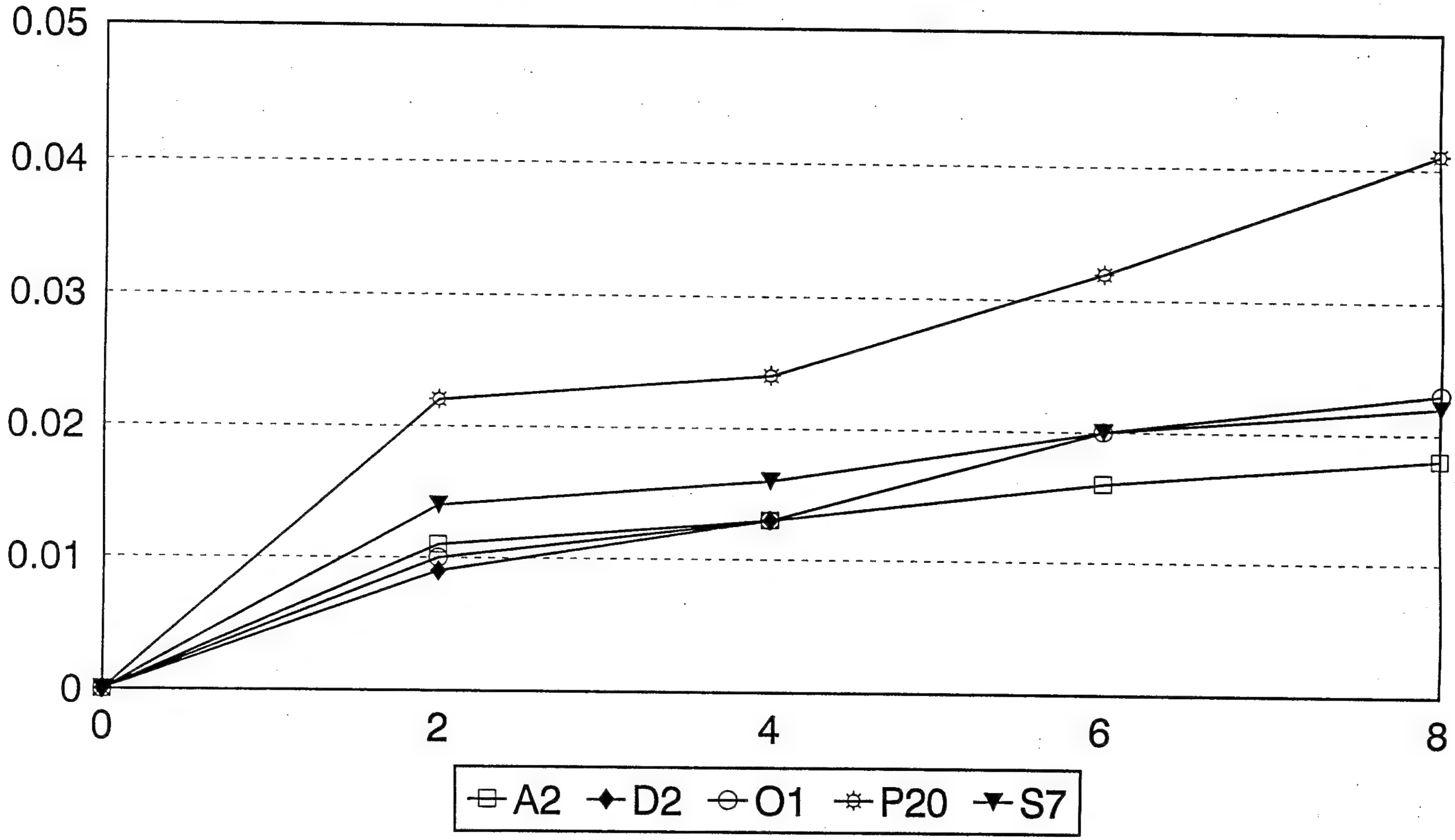
* Modified P-20 is French Grade 40CAD6-12



Tool Steel Nitriding
Fluidized Bed Process
Case Depth (inches)
0.05
0.04
0.03
0.02
0.01
0
Time (hours)
0
2
4
6
8
A2
D2
O1
P20
S7

Tool Steel Nitrocarburizing

Fluidized Bed Process



Appendix E: Heat Up Rates for Aluminum Alloys

Since the heat transfer coefficients for fluidized beds are about halfway between forced air convection and salt baths, the following table was developed for material soak times in fluidized beds. Soaking time begins when the parts are immersed in the fluidized beds, except when a heavy charge is loaded, and the temperature of the fluidized bed drops below the specified minimum, the time begins when the bed reaches the specified minimum.

All times in Minutes

Thickness	Minimum (Bare)	Max. Alclad
≤ 0.016	15	20
0.017 - 0.020	15	25
0.021 - 0.032	20	30
0.033 - 0.063	25	35
0.064 - 0.090	30	40
0.091 - 0.124	35	45
0.125 -0.250	40	55
0.251 -0.500	50	65
0.501 - 1.000	75	85
1.001 - 1.500	105	115
1.501 - 2.000	130	140
2.001 - 2.500	150	160
2.501 - 3.000	175	190
3.001 - 3.500	195	215
3.501 -4.000	215	235
For each extra 0.500, Add	20	25

Appendix F:

Aluminum Heat Treatments as Specified in MIL-H-6088

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
2024	extrusions	910-930	-W	-T3 6/, -T42	-T3510, T3511
	drawn tube	910-930	-W	-T3 6/, -T42	--
2048	sheet, plate	910-930	-W	-T4, -T42	-T351
2117	wire, rod, bar	925-950	-W	-T4	--
	rivets	890-950	-W	-T4	--
2124	plate	910-930	-W	-T4 2/, -T42	-T351
2219	sheet	985-1005	-W	-T31 6/, -T37 6/, -T42	--
	plate	985-1005	-W	-T31 6/, -T37 6/, -T42	-T351
	rivets	985-1005	-W	-T4	--
	wire, rod, bar	985-1005	-W	-T31 6/, -T42	-T351
	extrusions	985-1005	-W	-T31 6/, -T42	-T3510, -T3511
6010	sheet	1045-1065	-W	-T4	--
6013	sheet	1045-1065	-W	-T4	--
6061	sheet	960-1075 8/	-W	-T4, -T42	--
	plate	960-1075	-W	-T4, -T42	-T451
	wire, rod, bar	960-1075	-W	-T4, -T42	-T451

TABLE II. Solution heat-treating temperatures.

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
2011	wire, rod, bar	945-995	-W	-T3 6/, -T4	-T451
2014	flat sheet	925-945	-W	-T3 6/, -T42	--
	coiled sheet	925-945	-W	-T4, -T42	--
	plate	925-945	-W	-T4, -T42	-T451
	wire, rod, bar	925-945	-W	-T4	-T451
	extrusions	925-945	-W	-T4, -T42	-T4510, -T4511
	drawn tube	925-945	-W	-T4	--
2017	wire, rod, bar	925-950	-W	-T4	-T451
	rivets	925-950	-W	-T4	--
2024	flat sheet	910-930	-W	-T3 6/, -T361 6/, -T42	--
	coiled sheet	910-930	-W	-T4, -T42, -T3 6/	--
	rivets	910-930	-W	-T4	--
	plate	910-930	-W	-T4, -T42, -T361 6/	-T351
	wire, rod, bar	910-930 7/	-W	-T4, -T36 6/, -T42	-T351

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
6061	extrusions	960-1075	-W	-T4, -T42	-T4510, -T4511
	drawn tube	960-1075	-W	-T4, -T42	--
6063	extrusions	960-985	-W	-T4, -T42	-T4510, -T4511
	drawn tube	960-980	-W	-T4, -T42	N/A
6066	extrusions	960-1010	-W	-T4, -T42	-T4510, -T4511
	drawn tube	960-1010	-W	-T4, -T42	--
6262	wire, rod, bar	960-1050	-W	-T4	-T451
	extrusions	960-1050	-W	-T4	-T4510, -T4511
	drawn tube	960-1050	-W	-T4	—
6951	sheet	975-995	-W	-T4, -T42	—
7001	extrusions	860-880	-W	--	-W510 2/ W511 2/
7010	plate	880-900	-W		W51 2/
7039	sheet	840-860 9/	-W	--	--
	plate	840-860 9/	-W	--	-W51 2/
7049/ 7149	extrusions	860-885	-W	--	-W510 2/ -W511 2/
7050	sheet	880-900	-W		
	plate	880-900	-W	--	-W51 2/

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
7050	extrusions	880-900	-W	--	-W510 2/ -W511 2/
	wire, rod, rivets	880-900	-W	--	--
7075	sheet	860-930 10/	-W	--	--
	plate 11/	860-930	-W	--	-W51 2/
	wire, rod, bar 11/	860-930	-W	--	-W51 2/
	extrusions	860-880	-W	--	-W510 2/ -W511 2/
	drawn tube	860-880	-W	--	--
7150	extrusions	880-900	-W		-W510 2/ -W511 2/
	plate	880-895	-W		-W51 2/
7178	sheet 13/	860-930	-W		--
	plate 13/	860-910	-W	--	-W51 2/
	extrusions	860-880	-W	--	-W510 2/ -W511 2/
7475	sheet	880-970	-W	--	--
	plate	880-970	-W	--	--
7475 Alclad	sheet	880-945	-W	--	--

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Forgings 14/					
2014	die forgings	925-945	-W	-T4, -T41	--
	hand forgings	925-945	-W	-T4, -T41	-T452
2018	die forgings	940-970	-W	-T4, -T41	--
2024	die & hand forgings	910-930	-W	-T4	-T352
2025	die forgings	950-970	-W	-T4	--
2218	die forgings	940-960	-W	-T4, -T41	--
2219	die & hand forgings	985-1005	-W	-T4	-T352
2618	die & hand forgings	975-995	-W	-T4, -T41	--
4032	die forgings	940-970	-W	-T4	--
6053	die forgings	960-980	-W	-T4	--
6061	die & hand forgings	960-1075	-W	-T4, -T41	-T452
	rolled rings	960-1025	-W	-T4, -T41	-T452
6066	die forgings	960-1010	-W	-T4	--
6151	die forgings	950-980	-W	-T4	--
	rolled rings	950-980	-W	-T4	-T452

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Forgings 14/					
7049/ 7149	die & hand forgings	860-885	-W	--	-W52 2/
7050	die & hand forgings	880-900	-W	--	-W52 2/
7075	die & hand forgings	860-890 9/	-W	--	-W52 2/
	rolled rings	860-890 9/	-W	--	-W52 2/
7076	die & hand forgings	850-910	-W	--	--
7175	die forgings	15/	-W	--	--
	hand forgings	15/	-W	--	--

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Castings (all mold practices) 16/					
A201.0 18/	--	945 - 965 followed by 970 - 995	--	-T4	--
A206.0 (206) 18/	--	945-965 followed by 970-995	--	-T4	--
222.0 (122)	--	930 - 960	--	-T4	--
242.0 (142)	--	950 - 980	--	-T4, -T41	--
295.0 (195)	--	940 - 970	--	-T4	--
296.0 (B295.0)	--	935 - 965	--	-T4	--
319.0 (319)	--	920 - 950	--	-T4	--
328.0 (Red X-8)	--	950 - 970	--	-T4	--
333.0 (333)	--	930 - 950	--	-T4	--
336.0 (A332.0)	--	950 - 970	--	-T45	--
A336.0 (A332.0)	--	940 - 970	--	-T45	--
354.0 (354)	--	980 - 995	--	-T4	--

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Castings (all mold practices) 16/					
355.0 (355), C355.0	--	960 - 995	--	-T4	--
356.0 (356), A356.0 (A356)	-- --	980 - 1025 12/	-- --	-T4 -T4	-- --
357.0 (357), A357.0 (A357)	-- --	980 - 1025 12/	-- --	-T4 -T4	-- --
359.0 (359)	--	980 - 1010	--	-T4	
520.0 (220)	--	800 - 820	--	-T4	--
705.0 17/	--	--	--	T1 T5	-- --
707.0 17/	--	--	--	T1	--
712.0 17/	-- --	990 --	-- --	T4 T1	-- --
713.0 17/	--	--	--	T1	--
850.0 17/	--	--	--	T1	--
851.0 17/	--	--	--	T1	--
852.0 17/	--	--	--	T1	--

1/ The term "wire, rod, and bar" as used herein refers to rolled or cold finished wire, rod, and bar. The term "extrusions" refers to extruded wire, rod, bar, shapes, and tube.

2/ This temper is unstable and generally not available.

3/ Applies only to those alloys which will naturally age to a substantially stable condition. See Table VII for natural aging times.

4/ For rolled or extruded products, metal is stress relieved by stretching after quenching, and for forgings, metal is stress relieved by stretching or compression after quenching.

5/ When a difference between the maximum and minimum temperatures of a range listed herein exceeds 20° F, any 20° F temperature range (or 30° range for 6061) within the entire range may be utilized (see 3.5.1.5), provided that no exclusions or qualifying criteria are cited herein or in the applicable material specification.

6/ Cold working subsequent to solution heat treatment and prior to any precipitation heat treatment is necessary.

7/ Temperatures as low as 900° F may be used, provided that every heat treat lot is tested to show that the requirements of the applicable material specification are met, and analysis of test data to show statistic conformance to the specification limits is available for review.

8/ Maximum temperature for alclad 6061 sheet should not exceed 1000° F.

9/ Other temperatures may be necessary for certain sections, conditions and requirements.

10/ It must be recognized that under some conditions melting can occur when heating 7075 alloy above 900° F and that caution should be exercised to avoid this problem. In order to minimize diffusion between the cladding and the core, alclad 7075 sheet in thicknesses of 0.020 inch or less may be solution heat-treated at 850° to 930° F.

11/ For plate thicknesses over 4 inches and for rod diameters or bar thicknesses over 4 inches, a maximum temperature of 910° F is recommended to avoid melting.

12/ Heat treatment above 1010° F may require an intermediate solution heat treatment of one hour at 1000 - 1010° F to prevent eutectic melting of magnesium rich phases.

13/ Under some conditions melting can occur when heating this alloy above 900 degrees F.

14/ Unless otherwise indicated, hand forgings include rolled rings, and die forgings include impacts.

15/ Heat-treating procedures are at present proprietary among producers. At least one such procedure, is patented (U.S. Patent Number 3,791,876). (See 6.6).

16/ Former commercial designation is shown in parentheses.

17/ Unless otherwise specified solution heat treatment is not required. Castings should be quickly cooled after shake-out or stripping from molds, so as to obtain a fine tin distribution.

18/ In general, product should be soaked for two hours in the range 910-930° F prior to heating into the solution heat-treating range. Other presolution heat-treating temperature ranges may be necessary for some configurations and sizes.

TABLE III. Re-solution heat treatment of alclad alloys.

Thickness (inch)	Maximum number of re-solution heat treatments permissible 1/
Under 0.020	0
0.020 to 0.125 inclusive	1
Over 0.125	2

1/ One additional re-solution heat treatment is permitted if the heating rate is sufficiently rapid to keep product in conformance to 4.7.3.

TABLE V. Recommended soaking time for solution treatment of cast alloys.

Alloy	Soaking Time (hours)
A201.0 (201) and A206.0 (206)	2 at 910 – 930°F followed by 2-8 at 945-965 followed by 8-24 at 970-995
222.0 (122)	6 to 18 incl.
242.0 (142)	2 to 10 incl.
295.0 (195)	6 to 18 incl.
296.0 (13295.0)	4 to 12 incl.
319.0 (319)	6 to 18 incl.
328.0	12
336.0, A336.0	8 hr. then water quench to 150-212° F
354.0 (354)	10 to 12 incl.
355.0 (355) and C355.0 (C355)	6 to 24 incl.
356.0 (356) and A356.0 (A356)	6 to 24 incl.
357.0 (357) and A357.0 (A357)	8 to 24 incl.
359.0 (359)	10 to 14 incl.
520.0 (220)	18

TABLE VII. Recommended age-hardening heat-treating condition.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
2011	-W		Room temp.	96 Minimum	-T4, -T42
	-T3		310-330	14	-T8
	-T4		--	--	--
	-T451		--	--	--
2014	-W		Room temp.	96 Minimum	-T4, -T42
	-T3	flat sheet	310-330	18	-T6
	-T4, -T42	3/	340-360	10	-T6, -T62
	-T451 3/		340-360	10	-T651
	-T4510	extrusions	340-360	10	-T6510
	-T4511	extrusions	340-360	10	-T6511
2017	-W		Room temp.	96 Minimum	-T4
	-T4		--	--	--
	-T451		--	--	--
2024	-W		Room temp.	96 Minimum	-T4,-T42
	-T3	sheet and drawn tube	365-385	12	-T81
	-T4	wire, rod, bar	365-385	12	-T6
	-T3	extrusions	365-385	12	-T81
	-T36	wire	365-385	8	-T86
	-T42	sheet and plate	365-385	9	-T62
	-T42	sheet only	365-385	16	-T72
	-T42	other than sheet and plate	365-385	16	-T62
	-T351	sheet and plate	365-385	12	-T851
	-T361		365-385	8	-T861
	-T3510	extrusions	365-385	12	-T8510
	-T3511		365-385	12	-T8511
2048	-W		Room temp.	96 Minimum	-T4, -T42
	-T42	sheet and plate	365-385	9	-T62
	-T351		365-385	12	-T851
2117	-W	wire, rod, bar and rivets	Room temp.	96 Minimum	-T4
2124	-W	plate	Room temp.	96 Minimum	-T4, -T42
	-T4		365-385	9	-T6
	-T42		365-385	9	-T62
	-T351		365-385	12	-T851

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Age-hardening heat treatment 1/ Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Wrought products (excluding forgings):					
2219	-W		Room temp.	96 Minimum	-T4, -T42
	-T31	sheet	340-360	18	-T81
	-T31	extrusions	365-385	18	-T81
	-T31	rivets	340-360	18	-T81
	-T37	sheet	315-335	24	-T87
	-T37	plate	340-360	18	-T87
	-T42		365-385	36	-T62
	-T351		340-360	18	-T851
	-T351	rod and bar	365-385	18	-T851
	-T3510	extrusions	365-385	18	-T8510
	-T3511		365-385	18	-T8511
6010	-W	sheet	340-360	8	-T6
6013	-W	sheet	Room temp.	336	-T4
	-T4 22/		365-385	4	-T6
6061	-W		Room temp.	96 Minimum	-T4, -T42
	-T1	rods, bar, shapes and tube, extruded	340-360	8	-T5
	-T4 14/	except extrusions	310-330	18	-T6
	-T451		310-330	18	-T651
	-T42		310-330	18	-T62
	-T4	extrusions	340-360	8	-T6
	-T42		340-360	8	-T62
	-T4510		340-360	8	-T6510
	-T4511		340-360	8	-T6511
6063	-W	extrusions	Room temp.	96 Minimum	-T4, -T42
	-T1		350-370	3	-T5, -T52
	-T1		415-435	1-2	-T5, -T52
	-T4		340-360	8	-T6
	-T4		350-370	6	-T6
	-T42		340-360	8	-T62
	-T42		350-370	6	-T62
	-T4510		340-360	8	-T6510
	-T4511		340-360	8	-T6511
6066	-W	extrusions	Room temp.	96 Minimum	-T4, -T42
	-T4		340-360	8	-T6
	-T42		340-360	8	-T62
	-T4510		340-360	8	-T6510
	-T4511		340-360	8	-T6511

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
6262	-W		Room temp.	96 Minimum	-T4
	-T4	wire, rod, bar, drawn tube	330-350	8	-T6
	-T451		330-350	8	-T651
	-T4	extrusions	340-360	12	-T6
	-T4510		340-360	12	-T6510
	-T4511		340-360	12	-T6511
6951	-W		Room temp.	96 Minimum	-T4, -T42
	-T4	sheet	310-330	18	-T6
	-T42		310-330	18	-T62
7001	-W	extrusions	240-260	24	-T6
	-W510		240-260	24	-T6510
	-W511		240-260	24	-T6511
7010	-W51 21/	plate	240-260 plus 330-350	6-24 6-15	-- T7651
			240-260 plus 330-350	6-24 9-18	T7451 17/
			240-260 plus 330-350	6-24 15-24	T7351
7039	-W 15/	sheet	165-185 plus 310-330	16 14	-T61
	-W51 15/	plate	165-185 plus 310-330	16 14	-T64
7049, 7149	-W511	extrusions	Room temp. followed by 240-260 followed by 320-330	48 24 12-14	-T76510, -T76511
			Room temp. followed by 240-260 followed by 325-335	48 24-25 12-21	-T73510, -T73511 19/

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
7050	-W51 8/	plate	240-260 plus 315-335	3-6 12-15	-T7651
			240-260 plus 315-335	3-6 24-30	-T7451 17/
	-W510 8/	extrusions	240-260 plus 315-335	3-8 15-18	-T76510
	-W511 8/		240-260 plus 315-335	3-8 15-18	-T76511
	-W 8/	wire, rod, rivets	245-255 plus 350-360	4 min. 8 min.	-T73
7075	-W 7/		240-260	24	-T6, -T62
	-W 5/ 8/ 11/	sheet and plate	215-235 plus 315-335	6-8 24-30	-T73
	-W 8/ 11/		240-260 plus 315-335	3-5 15-18	-T76
	-W 6/ 8/ 11/	wire, rod, bar	215-235 plus 340-360	6-8 8-10	-T73
	-W 5/ 8/ 11/	extrusions	215-235 plus 340-360	6-8 6-8	-T73
	-W 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76
	-W51 5/ 8/, 11/	plate	215-235 plus 315-335	6-8 24-30	-T7351

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
7075	W51 8/ 11/	plate	240-260 plus 315-335	3-5 15-18	-T7651
	-W51 10/		240-260	24	-T651
	-W51 6/ 8/ 11/	wire, rod, bar	215-235 plus 340-360	6-8 8-10	-T7351
	-W510 7/	extrusions	240-260	24	-T6510
	-W511 7/		240-260	24	-T6511
	-W510 5/ 8/ 11/		215-235 plus 340-360	6-8 6-8	-T73510
	-W511 5/ 8/ 11/		215-235 plus 340-360	6-8 6-8	-T73511
	-W510 5/ 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76510
	-W511 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76511
	-T6 8/	sheet	315-335	24-30	-T73
	-T6 8/	wire, rod, bar	340-360	8-10	-T73
	-T6 8/	extrusions	340-360	6-8	-T73
			310-330	18-21	-T76
	-T651 8/	plate	315-335	24-30	-T7351
			315-335	15-18	-T7651

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F 4/	Age-hardening heat treatment 1/ Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Wrought products (excluding forgings):					
	-T651 8/	wire, rod, bar	340-360	8-10	-T7351
	-T6510 8/	extrusions	340-360	6-8	-T73510
			310-330	18-21	-T76510
	-T6511 8/		340-360	6-8	-T73511
			310-330	18-21	-T76511
7150	W510, W511	extrusions	240-260 plus 310-330	8 4-6 20/	-T6510, -T6511
	W51	plate	240-260 plus 300-320	24 12	T651
7178	-W		240-260	24	-T6, -T62
	-W 8/ 11/	sheet	240-260 plus 315-335	3-5 15-18	-T76
	-W 8/ 11/	extrusions	240-260 plus 310-330	3-5 18-21	-T76
	-W51	plate	240-260	24	-T651
	-W51 8/ 11/		240-260 plus 315-335	3-5 15-18	-T7651
	-W510	extrusions	240-260	24	-T6510
	-W510 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76510

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Wrought products (excluding forgings):					
7178	-W511	extrusions	240-260	24	-T6511
	-W511 8/ 11/		240-260 followed by 310-330	3-5 18-21	-T76511
7475	-W	sheet	240-260 followed by 315-325	3 8-10	-T761
	-W51	plate	240-260	24	-T651
7475 Alclad	-W	sheet	250-315	3	-T61

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Age-hardening heat treatment 1/ Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Forgings:					
2014	-W		Room temp.	96 Minimum	-T4
	-T4		330-350	10	-T6
	-T41		340-360	5-14	-T61
	-T452	hand forgings	330-350	10	-T652
2018	-W	die forgings	Room temp.	96 Minimum	-T4
	-T41	die forgings	330-350	10	-T61
2024	-W	die & hand forgings	Room temp.	96 Minimum	-T4
	-W52	hand forgings	Room temp.	96 Minimum	-T352
	-T4	die & hand forgings	365-385	12	-T6
	-T352	hand forgings	365-385	12	-T852
2025	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
2218	-W	die forgings	Room temp.	96 Minimum	-T4, -T41
	-T4	die forgings	330-350	10	-T61
	-T41	die forgings	450-470	6	-T72
2219	-W		Room temp.	96 Minimum	-T4
	-T4		365-385	26	-T6
	-T352	hand forgings	340-360	18	-T852

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Forgings:					
2618	-W		Room temp.	96 Minimum	-T4
	-T41	die forgings	380-400	20	-T61
4032	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
6053	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
6061	-W	die & hand forgings	Room temp.	96 Minimum	-T4
	-T41	die & hand forgings	340-360	8	-T61
	-T452	rolled rings & hand forgings	340-360	8	-T652
6066	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	340-360	8	-T6
6151	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
	-T452	rolled rings	330-350	10	-T652
7049	-W -W52	die & hand forgings	Room temp. followed by 240-260 followed by 320-330	48 24 10-16	-T73, -T7352

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Forgings:					
7050	-W	die forgings	240-260 plus 340-360	3-6 6-12	-T74 16/
	-W52	hand forgings	240-260 plus 340-360	3-6 6-8	-T7452 18/
7075	-W		240-260	24	-T6
	-W 8/ 11/		215-235 plus 340-360	6-8 8-10	-T73
	-W52	hand forgings	240-260	24	-T652
	-W52 8/ 11/		215-235 plus 340-360	6-8 6-8	-T7352
	-W51	rolled rings	215-235 plus 340-360	6-8 6-8	-T7351
	-W	die & hand forgings	215-235 plus 340-360	6-8 6-8	-T74 16/
7076	-W	die & hand forgings	265-285	14	-T6
7149	-W	die & hand forgings	Room temp.	48	
	-W52		240-260 plus 320-340	24 10-16	-T73, -T7352
7175	-W52	hand forgings	240-260	24	-T652
	-W	die & hand forgings	215-235 plus 340-360	6-8 6-8	-T74 16/

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Castings (all mold practices)					
201.0	-T4		300-320	10-24	-T6
A201.0 (201)	-T4		360-380	5 minimum	-T7
A206.0 (206)	-T4		380-400	5 minimum	-T7
222.0	-F		330-350	16-22	-T551
(122)	-T4		380-400	10-12	-T61
	-T4		330-350	7-9	-T65
242.0	-F		320-350	22-26	-T571
(142)	-T41		400-450	1-3	-T61
295.0 (195)	-T4		300-320	12-20	-T62
296.0	-T4		300-320	1-8	-T6
(B295.0)	-T4		490-510	4-6	-T7
319.0 (319)	-T4		300-320	1-6	-T6
328.0 (Red X-8)	-T4		300-320	2-5	-T6
333.0 (333)	-F		390-410	7-9	-T5
	-T4		300-320	2-5	-T6
	-T4		490--510	4-6	-T7
336.0 (A332.0)	-T45		300-350	14-18	-T65

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Castings (all mold practices)					
354.0 (354)	-T41		300-320	10-12	-T61
	-T41		330-350	6-10	-T62
355.0 (355) and C355.0 (C355)	-F		430-450	7-9	-T51
	-T4		300-320	1-6	-T6
	-T4		300-320	10-12	-T61
	-T4		330-350	14-18	-T62
	-T4		430-450	3-5	-T7
	-T4		465-485	4-6	-T71
356.0 (356) and A356.0 (A356)	-T4				
	-F		430-450	6-12	-T51
	-T4		300-320	1-6	-T6
	-T4		300-320	6-10	-T61
357.0 (357) and A357.0 (357)	-T4		300-340	2-12	-T6
359.0 (359)	-T4		300-320	8-12	-T61
	-T41		330-350	6-10	-T62
520.0 (220)	-T4		300-320	20-12	-T61
	-T41		330-350	6-10	-T62
705.0 (603)	-W		200-220 or Room temp.	10 21 days	-T5
707.0 (607)	-F		300-320 or Room temp.	3-5 21 days	-T5

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Castings (all mold practices)					
712.0 (D712.0)	-F		345-365 or Room temp.	9-11 21 days	-T5
	-F		Room temp.	96 Minimum	-T1
713.0 (613)	-F		240-260 or Room temp.	16 21 days	-T5
850.0 (750)	-F		420-440	7-9	-T5
851.0 (A850.0)	-F		420-440	7-9	-T5
852.0 (B850.0)	-F		420-440	7-9	-T5

1/ To produce the stress-relieved tempers, metal which has been solution heat-treated in accordance with Table II (-W temper) must be stretched or compressed as required before aging. In instances where a multiple stage aging treatment is used, the metal may be, but need not be, removed from the furnace and cooled between aging steps.

2/ The time at temperature will depend on time required for load to reach temperature. The times shown are based on rapid heating with soaking time measured from the time the load reached the minimum temperature shown.

3/ Alternate treatment of 18 hours at 305° - 330 F may be used for sheet and plate.

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

4/ When the interval of the specified temperature range exceeds 20° F, any 20° temperature range (or 30° range for 6061) within the entire range may be utilized provided that no exclusions or qualifying criteria are cited herein or in the applicable material specification.

5/ Alternate treatment of 6 to 8 hours at 215° to 235° F followed by a second stage of 14 to 18 hours at 325° to 345° F may be used providing a heating-up rate of 25° F per hour is used.

6/ Alternate treatment of 10 to 14 hours at 340° to 360° F may be used providing a heating-up rate of 25° F per hour is used.

7/ For extrusions an alternate three-stage treatment comprised of 5 hours at 200° to 220° F followed by 4 hours at 240° to 260° F followed by 4 hours at 290° to 310° F may be used.

8/ The aging of aluminum alloys 7049, 7050, 7075 and 7178 from any temper to the T7 type tempers requires closer control on aging practice variables such as time, temperature, heating-up rates, etc., for any given item. In addition to the above, when re-aging material in the T6 temper series to the T7 type temper series, the specific condition of the T6 temper material (such as its property level and other effects of processing variables) is extremely important and will affect the capability of the re-aged material to conform to the requirements specified for the applicable T7 type tempers.

9/ Old or former commercial designation is shown in parentheses.

10/ For plate, an alternate treatment of 4 hours at 195° - 215 degrees F followed by a second stage of 8 hours at 305° - 325° F may be used.

11/ With respect to -T73, -T7351, -T73510, -T73511, -T7352, -T76, -T76510 and -T76511 tempers, a license has been granted to the public under U.S. Patent 3,198,676 and these times and temperatures are those generally recommended by the patent holder. Counterpart patents exist in several countries other than the United States. Licenses to operate under these counterpart patents should be obtained from the patent holder.

12/ A heating-up rate of 50° - 75° F per hour is recommended.

13/ The 96 hour minimum aging time required for each alloy listed with temper designation W is not necessary if artificial aging is to be employed to obtain tempers other than that derived from room temperature aging. (For example, natural aging (96 hours) to achieve the -T4 or -T42 temper for 2014 alloy is not necessary prior to artificial aging to obtain a -T6 or -T62 temper.)

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

14/ An alternate treatment comprised of 8 hours at 350° F also may be used.

15/ A heating-up rate of 35° F per hour from 135° F is recommended.

16/ Formerly designated as T736 temper.

17/ Formerly designated as T73651 temper.

18/ Formerly designated as T73652 temper.

19/ Longer times are to be used with section thicknesses less than 2 inches.

20/ Soak time of 4 hours for extrusions with leg thickness less than 0.8 inch and 6 hours for extrusions having thicker legs.

21/ An alternative treatment is to omit the first stage and heat at a rate no greater than 36° F/hr.

22/ Doesn't require the 14-day room temperature age.

Appendix G: Titanium Heat Treatments per MIL-H-81200

SOLUTION AND AGE HEAT TREATMENTS

Alloy	Solution Treatment Temp.	Time (min)[F]		Cooling	Aging Treatment Temp.	Time (hr)
8Al-1Mo-1V	1650-1850[A]	20/90		Air Cool	1000-1150	8/24
6Al-4V	1650-1775	2/90	20/120	Water Q	900-1275	2/8
6Al-6V-2Sn	1550-1700	2/90	20/90	Water Q	875-1150	2/10
6Al-2Sn-4Zr-2Mo	Product Dep.[B]	2/60	20/120	Air Cool	1050-1150	2/8
6Al-2Sn-4Zr-6Mo	1500-1675	2/90	20/120	Water Q[C]	1050/1250	4/8
11Sn-5Zr-2Al-1Mo	1625-1675[D]		20/120	Air Cool	900-1000	20/30
6Al-2Sn-2Zr-2Mo 2Cr-0.25Si	1600-1700	2/60		Water Q	900-1250	2/10
5Al-2Sn-2Zr-4Mo-6Cr	1450-1500[D]		20/120	Water Q	1100-1250	4/8
13V-11Cr-3Al	1400-1500	2/60	20/60	Water Q	825-975	2/60
3Al-8V-6Cr-4Mo-4Zr	1450-1700	2/60	20/90	Water Q	875-1150	2/24
15V-3Al-3Cr-3Sn	1400-1500[E]	2/30	20/60	Air Cool	900-1250	2/24
10V-2Fe-3Al	1300-1425[D]	60/120		Water Q	900-1150	8/10

A. Bars, Forgings, and Castings Only.
B. 1500-1675 for Sheet, Plate, and Strip: 1650-1800 for Bars, Forgings, and Castings
C. Air cooling of thin sections is permitted by specification.
D. No solution heat treating cycle is specified for Sheet, Plate, and Strip.
E. No solution heat treating cycle is specified for Bars, Forgings, and Castings.
F. When two time ranges specified, the first is for Sheet, Plate, and Strip: the second is for Bars, Forgings, and Castings.

ANNEALING

Alloy	Sheet, Strip, and Plate Annealing Treatment Temp.	Time	Cooling	Casting & Forging Stress Relief Treatment Temp.	Time (hr)	Cooling
Comm. Pure	1200-1500	15/120	Air Max	1200 - 1450	60/120	Cycle[A]
5Al-2.5Sn	1300 - 1550	10/120	Air	1300 - 1550	60/240	Air
5Al-2.5 ELI	1300 - 1650	10/120	Air	1300 - 1550	60/240	Air
6Al-2Cb-1Ta-0.8Mo	1450 - 1650	30/120	Air Max	1450 - 1650	60/120	Air Max
8Al-1Mo-1V	1400 - 1500	60/480	Cycle[B]	1650 - 1850	60/120	Cycle[C]
3Al-2.5V	1200 - 1450	30/120	Air Max	1200 - 1450	60/180	Air Max
6Al-4V	1300 - 1600	15/60	Cycle[D]	1300 - 1450	60/120	Air
6Al-4V ELI	1300 - 1600	15/60	Cycle[D]	1300 - 1450	60/120	Air
6Al-6V-2Sn	1300 - 1500	10/120	Air Max	1300 - 1450	60/120	Air Max
6Al-2Sn-4Zr-2Mo	1600 - 1700	Note E	Note E	1600 - 1700	Note E	Note E
6Al-2Sn-4Zr-6Mo	N/A	N/A	N/A	1500 - 1675	60/120	Note F
11Sn-5Zr-2Al-1Mo	N/A	N/A	N/A	1625 - 1675	60/120	Air Min
6Al-2Sn-2Zr-2Cr-2Mo	1275 - 1600	15/360	Air	1275 - 1600	15/360	Air
13V-11Cr-3Al	1400 - 1500	10/60	Note F	1400 - 1500	30/120	Note F
3Al-8V-6Cr-4Mo-4Zr	1400 - 1700	10/60	Note F	1400 - 1700	30/120	Note F
15V-3Al-3Cr-3Sn	1400 - 1500	3/30	Note F	N/A	N/A	N/A
10V-2Al-3Fe	N/A	N/A	N/A	Note F	Note F	Note F

NOTES

A. For bars and forging, air cool to 1100, then retreat at 1100 for 8 hours and air cool.

B. Furnace cool to 900 Max - duplex anneal requires second anneal at 1450 for 15 minutes then air cool.

C. Stabilize at 1100 for 8 hours then air cool.

D. When duplex anneal specified, heat to beta transus minus 50 top 75°F for 1 to 2 hrs (bars, forgings, and plate), air cool min., reheat 1300 - 1400 for 1 - 2 hours and air cool.

E. For plate, heat 30/120, air cool, reheat to 1450 for 15 and air cool. For sheet heat 10/60, air cool, reheat to 1100 for 480 and air cool. For bars and forgings, 25 to 50°F below beta transus for 10/60, then air cool, reheat to 1100 for 480 and air cool.

F. Air cool then age at a temperature to develop required properties.

STRESS RELIEF

Alloy	Temp.	Time (min)
Commercially Pure	900 - 1100	15/240
5Al-2.5Sn	1000 - 1200	15/360
5Al-2.5Sn ELI	1000 - 1200	15/360
6Al-2Cb-1Ta-0.8Mo	1100 - 1400	15/60
8Al-1Mo-1V	1100 - 1400	10/75
11Sn-5Zr-2Al-1Mo	900 - 1000	120/480
3Al-2.5V	700 - 1100	15/240
6Al-4V	900 - 1200	60/240
6Al-4V ELI	900 - 1200	60/240
6Al-6V-2Sn	900 - 1200	60/240
6Al-2Sn-4Zr-2Mo	900 - 1200	60/240
5Al-2Sn-2Zr-4Mo-4Cr	900 - 1200	60/240
6Al-2Sn-2Zr-2Mo-2Cr-0.25Si	900 - 1200	60/240
13V-11Cr-3Al	1300 - 1350	30/60
3Al-8V-6Cr-4Mo-4Zr	1300 - 1400	10/60
15V-3Al-3Cr-3Sn	1450 - 1500	30/60
10V-2Fe-3Al	1250 - 1300	30/60

Appendix H: Heat Treatment of Magnesium Alloys (From Metals Handbook, Ninth Edition, Volume 4 - Heat Treating).

Annealing

Alloy	Temper Condition	Temperature
AZ31B	F, H10, H11, H23, H24, H25	650
AZ31C	F	650
AZ61A	F	650
AZ80A	F, T5, T6	725
HK31A	H24	750
HM21A	T5,T8, T81	850
HM31A	T5	850
ZK60A	F, T5, T6	550

Time at temperature is 1 hr minimum.

Stress Relief

	Annealed Sheet		Hard Roll Sheet		Extrusions & Forgings	
Alloy	Temp(°F)	Time (min)	Temp	Time	Temp	Time
AZ31B	650	120	300	60		
AZ31B-F					500	15
AZ61A	650	120	400	60		
AZ61B-F					500	15
AZ80A-F					500	15
AZ80T5					400	60
HK31A	650	60	550	30		
HM21A-T5					700	30
HM21A-T8			700	30		
HM21A-T81			750	30		
HM31A-T5					800	60
ZK60A-F	450	180			500	15
ZK60A-T5					300	60

The aging treatments described include F which is as Fabricated, T4 which is solution treated only, T5 which is artificially aged only, T6 which is solution treated and artificially aged, and T8 which is solution treated, cold worked, and artificially aged. Quenching is either air of forced air, unless otherwise noted. Recommended solution treating and aging cycles are as follows:

MAGNESIUM HEAT TREATMENT IN A FLUIDIZED BED

For castings up to 51 mm (2 in.) in section thickness; heavier sections may require longer times at temperature.

Alloy	Final temper	Aging(a) Temperature °C, ±6(b)	Aging(a) Temperature °F, ±10(b)	Aging(a) Time, h	Solution treating(c) Temperature °C, ±6(b)	Solution treating(c) Temperature °F, ±10(b)	Solution treating(c) Time, h	Solution treating(c) Maximum temperature °C	Solution treating(c) Maximum temperature °F	Aging after solution treating Temperature °C, ±6(b)	Aging after solution treating Temperature °F, ±10(b)	Aging after solution treating Time, h
Magnesium-aluminum-zinc alloys(d)												
AM100A	T5	232	450	5	...	...	...	...	...	...	...	...
	T4	...	...	...	424(e)	795(e)	16–24(e)	432	810	...	...	...
	T6	...	...	...	424(e)	795(e)	16–24(e)	432	810	232	450	5
	T61	...	...	...	424(e)	795(e)	16–24(e)	432	810	218	425	25
AZ63A	T5	260(f)	500(f)	4(f)	...	...	...	...	...	...	...	...
	T4	...	...	...	385	725	10–14	391	735	...	...	...
	T6	...	...	...	385	725	10–14	391	735	218(f)	425(f)	5(f)
AZ81A	T4	...	...	...	413(e)	775(e)	16–24(e)	418	785	...	...	...
AZ91C	T5	168(g)	335(g)	16(g)	...	...	...	...	...	...	...	...
	T4	...	...	...	413(e)	775(e)	16–24(e)	418	785	...	...	...
	T6	...	...	...	413(e)	775(e)	16–24(e)	418	785	168(h)	335(h)	16(h)
AZ92A	T5	260	500	4	...	...	...	...	...	...	...	...
	T4	...	...	...	407(j)	765(j)	16–24(j)	413	775	...	...	...
	T6	...	...	...	407(j)	765(j)	16–24(j)	413	775	218	425	5
Magnesium-zirconium alloys												
EZ33A	T5	216(k)	420(k)	5(k)	...	...	...	...	...	...	...	...
HK31A(m)	T6	...	...	...	566	1050	2	571	1060	204	400	16
HZ32A	T5	316	600	16	...	...	...	...	...	...	...	...
QE22A(n)	T6	...	...	...	527	980	4–8	538	1000	204	400	8
QH21A(n)	T6	...	...	...	527	980	4–8	538	1000	204	400	8
ZE41A	T5	329(p)	625(p)	2(p)	...	...	...	...	...	...	...	...
ZE63A(q)	T6	...	...	...	480	895	10–72	491	915	141	285	48
ZH62A	T5	329	625	2	...	...	...	...	...	...	...	...
	plus:	177	350	16	...	...	...	...	...	..	...	...
ZK51A	T5	177(r)	350(r)	12(r)	...	...	...	...	...	...	...	...
ZK61A	T5	149	300	48	...	...	...	...	...	...	...	...
	T6	...	...	...	499(s)	930(s)	2(s)	502	935	129	265	48

(a) Aging of castings to the T5 temper is done from the as-cast condition. (b) Except where quoted differently. (c) After solution treatment and before subsequent aging, castings are cooled to room temperature by fast fan cooling, except where otherwise indicated. Use carbon dioxide or sulfur dioxide atmosphere above 400 °C (750 °F). (d) For solution treating, Mg-Al-Zn alloys are loaded into the furnace at 260 °C (500 °F) and brought to temperature over a 2-h period at a uniform rate of temperature increase. (e) Alternative treatment, to prevent germination (excessive grain growth): 6 h at 413 ± 6 °C (775 ± 10 °F), 2 h at 352 ± 6 °C (665 ± 10 °F), 10 h at 413 ± 6 °C (775 ± 10 °F). (f) Alternative treatment: 5 h at 232 ± 6 °C (450 ± 10 °F). (g) Alternative treatment: 4 h at 216 ± 6 °C (420 ± 10 °F). (h) Alternative treatment: 5–6 h at 216 ± 6 °C (420 ± 10 °F). (j) Alternative treatment, to prevent germination (excessive grain growth): 6 h at 407 ± 6 °C (765 ± 10 °F), 2 h at 352 ± 6 °C (665 ± 10 °F), 10 h at 407 ± 6 °C (765 ± 10 °F). (k) Alternative treatment, which can be used where maximum resistance to creep at elevated temperature is not of prime importance: 2 h at 343 ± 6 °C (650 ± 10 °F). (m) Alloy HK31A castings must be loaded into the furnace already at temperature and brought back to temperature as quickly as possible. (n) Quench from solution-treating temperature either in water at 65 °C (150 °F) or in other suitable quenching medium. (p) This treatment is adequate for development of satisfactory properties; it may be followed by 16 h at 177 ± 6 °C (350 ± 10 °F), to provide very slight improvements in mechanical properties. (q) Alloy ZE63A must be solution treated in a special hydrogen atmosphere, because its mechanical properties are developed through hydriding of some of its alloying elements. Hydriding time depends on section thickness; as a guide, 6.4-mm (1/4-in.) sections require approximately 10 h, and 19-mm (3/4-in.) sections require about 72 h. Following solution treatment, ZE63A should be quenched in oil, water spray or air blast. (r) Alternative treatment: 8 h at 218 ± 6 °C (425 ± 10 °F). (s) Alternative treatment: 10 h at 482 ± 6 °C (900 ± 10 °F).

Appendix I: Required Heat Up Times for Magnesium Alloys

All times in Minutes

Thickness	Minimum (Bare)	Max. Alclad
≤ 0.016	18	24
0.017 - 0.020	18	30
0.021 - 0.032	24	36
0.033 - 0.063	30	42
0.064 - 0.090	36	48
0.091 - 0.124	42	54
0.125 - 0.250	48	66
0.251 - 0.500	60	78
0.501 - 1.000	90	102
1.001 - 1.500	126	138
1.501 - 2.000	156	168
2.001 - 2.500	180	192
2.501 - 3.000	210	228
3.001 - 3.500	234	258
3.501 - 4.000	258	288
For each extra 0.500, Add	24	30

Appendix J: Heat Treatment of Copper Alloys

ANNEALING

ALLOY	TEMP °F	SPECIFIED COOLING METHOD
C21000	800 - 1450	NONE
C22000	800 - 1450	NONE
C22600	800 - 1400	NONE
C23000	800 - 1350	NONE
C24000	800 - 1300	NONE
C26000	800 - 1400	NONE
C26800	800 - 1300	NONE
C27000	800 - 1300	NONE
C27400	800 - 1300	NONE
C28000	800 - 1100	NONE
C31400	800 - 1200	NONE
C33000	800 - 1200	NONE
C33500	800 - 1200	NONE
C33200	800 - 1200	NONE
C34200	800 - 1200	NONE
C35300	800 - 1200	NONE
C34000	800 - 1200	NONE
C35000	800 - 1200	NONE
C35600	800 - 1200	NONE
C36000	800 - 1100	NONE
C36500	800 - 1100	NONE
C36600	800 - 1100	NONE
C36700	800 - 1100	NONE
C36800	800 - 1100	NONE
C37000	800 - 1200	NONE
C37700	800 - 1100	NONE
C38500	800 - 1100	NONE
C44300	800 - 1100	NONE
C44400	800 - 1100	NONE
C44500	800 - 1100	NONE
C46200	800 - 1100	NONE
C48200	800 - 1100	NONE
C48500	800 - 1100	NONE
C50500	900 - 1200	NONE
C51000	900 - 1250	NONE
C52100	900 - 1250	NONE
C54200	900 - 1250	NONE
C53200	900 - 1250	NONE
C53400	900 - 1250	NONE
C54400	900 - 1250	NONE
C60600	1000 - 1200	NONE
C60800	1000 - 1200	NONE
C61000	1100 - 1250	NONE

ANNEALING (Continued):

ALLOY	TEMP °F	SPECIFIED COOLING METHOD
C61300	1400 - 1600	NONE
C61400	1400 - 1600	NONE
C61800	1100 - 1200	WATER QUENCH (FAST COOL)
C61900	1100 - 1200	WATER QUENCH (FAST COOL)
C62400	1100 - 1200	WATER QUENCH (FAST COOL)
C63000	1200 - 1300	AIR COOL
C63200	1250 - 1350	AIR COOL
C64200	1200 Min.	NONE
C65100	900 - 1250	NONE
C65500	900 - 1300	NONE
C67000	800 - 1100	NONE
C67500	800 - 1100	NONE
C68700	800 - 1100	NONE
C70600	1100 - 1500	NONE
C71500	1200 - 1500	NONE
C75200	1100 - 1500	NONE
C75700	1100 - 1500	NONE
C77000	1100 - 1500	NONE

STRESS RELIEF

ALLOY	TEMPERATURE °F
C21000	375
C22000	400
C23000	450
C24000	500
C26000	500
C27000	500
C28000	400
C36000	475
C44300	550
C44400	550
C44500	550
C51000	400
C52100	400
C63100	650
C61400	650
C65500	650
C70600	500
C71500	500
C75200	500

IN ALL CASES HOLD AT TEMPERATURE FOR 1 HOUR.

SOLUTION AND AGE OR TEMPER TREATMENTS

	SOLUTION		AGING	
ALLOY	TEMP °F	TIME	TEMP °F	TIME (hr)
Precipitation Hardenable Alloys				
C15000	1650		795 - 885	1
C15000	1795		400 - 550	3
C18000	1650 - 1705		800 - 1000	2 - 3
C18200	1795 - 1830		800 - 930	2 - 4
C18400	1795 - 1830		800 - 930	2 - 4
C18500	1795 - 1830		800 - 930	2 - 4
C81500	1795- 1830		800 - 930	2 - 4
C81540	1650 - 1705		800 - 1000	2 - 3
C94700	1425 - 1475	2	580 - 620	5
C94800			580 - 620	6 - 17
C96600	1825	1	950	3
C99400	1625	1	900	1
C99500	1625	1	900	1
Spinodally hardened alloys				
C71900	1650 - 1740	.5 - 2	800 - 1400	1 - 2
C72600	1300 - 1400	.5 - 2	660	1.5
C72700	1350 - 1450	.5 - 2	660	1.5
C72800	1480 - 1550	.5 - 2	660	3 - 6
C72900	1500 - 1575	.5 - 2	660	1.5
Quench and Temper for Complex α-β Alloys				
C62400	1600		1150	2
C63000	1575		1200	2
C95300	1575		1150	2
C95400	1600		1150	2
C95500	1575		1200	2

NOTE: Solution treating is immediately followed by water quenching.

CU-BE ALLOYS FROM MIL-H-7199

SOLUTION HEAT TREATMENTS AS FOLLOWS:

Alloy 170 & 172	1450 for 1 hr/in	Immediately Water Quench
Alloy 175	1700 for 1 hr/in	Immediately Water Quench

FOR COPPER ALLOY NUMBERS 170 AND 172

Age Hardening Time-Temperature Conditions (see 3.7.2.3.1) and
Material Temper-Designations

MATERIAL FORM	BEFORE AGE HARDENING TEMPER DESIGNATION	AGE HARDENING Time (Hrs.)	AGE HARDENING Temperature (°F)	AFTER AGE HARDENING TEMPER DESIGNATION
Plate, Sheet or Strip	A 1/4 H b/ 1/2 H b/ H b/	3 2 2 2	600±5 600±5 600±5 600±5	AT 1/4 HT c/ 1/2 HT c/ HT c/
Forgings, a/, Rod and Bar	A	3	600±5	AT
3/4 inch or less	H b/	2	600±5	HT c/
over 3/4 inch	H b/	3	600±5	HT c/
Wire	A 1/4 H b/ 1/2 H b/ 3/4 H b/	3 2 1-1/2 1	600±5 600±5 600±5 600±5	AT 1/4 HT c/ 1/2 HT c/ 3/4 HT c/

a/ Forgings are "A" or "AT" only
b/ See 3.7.2.2.1
c/ See 3.7.3

FOR COPPER ALLOY NUMBER 175

Age Hardening Time-Temperature Conditions (see 3.7.2.3.1) and
Material Temper-Designations

MATERIAL FORM	BEFORE AGE HARDENING TEMPER DESIGNATION	AGE HARDENING Time (Hrs.)	AGE HARDENING Temperature (°F)	AFTER AGE HARDENING TEMPER DESIGNATION
Plate, Sheet or Strip	A 1/2 H b/ H b/	3 2 2	900±5 900±5 900±5	AT 1/2 HT c/ HT c/
Forgings, a/ Rod and Bar	A	3	900±5	AT
3/4 inch or less	H b/	2	900±5	HT c/
over 3/4 inch	H b/	3	900±5	HT c/
Wire	A H b/	3 2	900±5 900±5	AT HT c/

a/ Forgings are "A" or "AT" only
b/ See 3.7.2.2.1
c/ See 3.7.3

Figure 1: Fluidized Bed Schematic Diagram

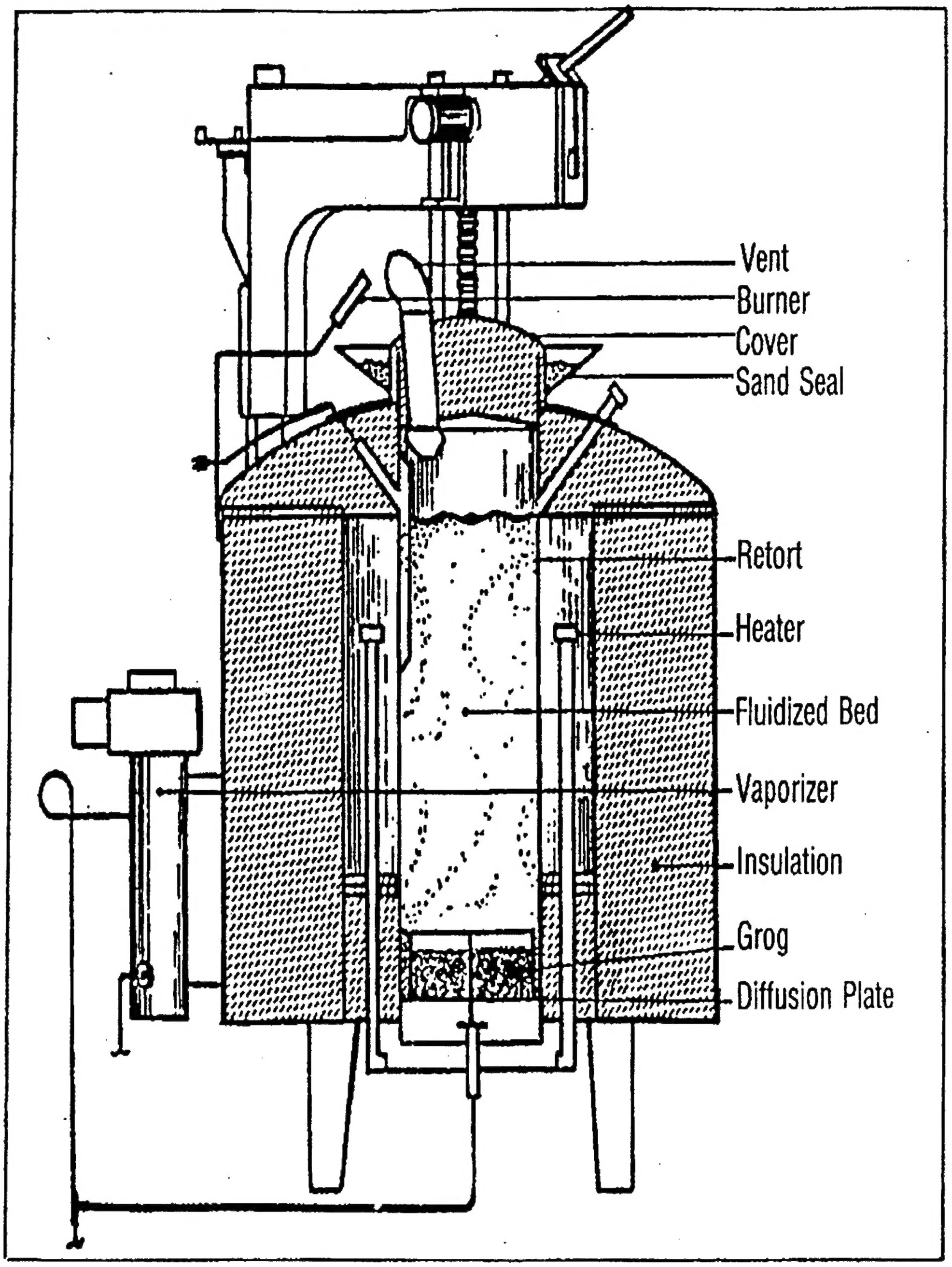
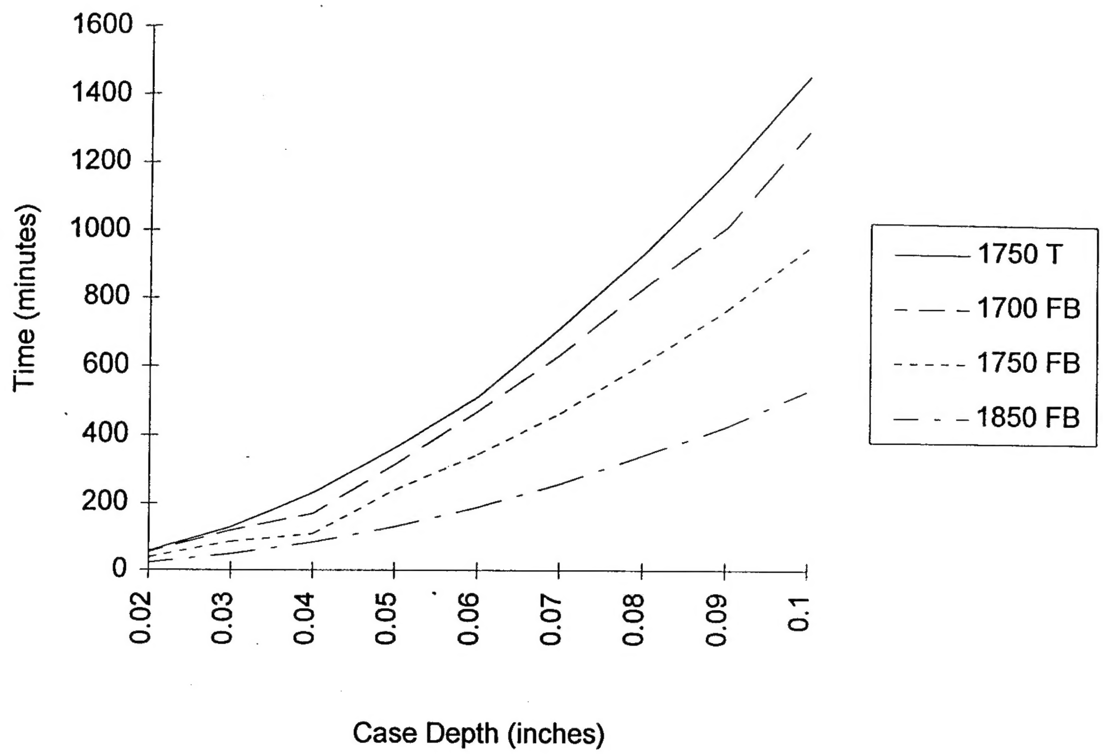


Figure 2: Traditional vs. Fluidized Bed Carburization



Note: The fluidized bed cycle times are the sum total of the boost segment time and the diffuse segment time.

Figure 3: Traditional vs. Fluidized Bed Nitriding on 4340

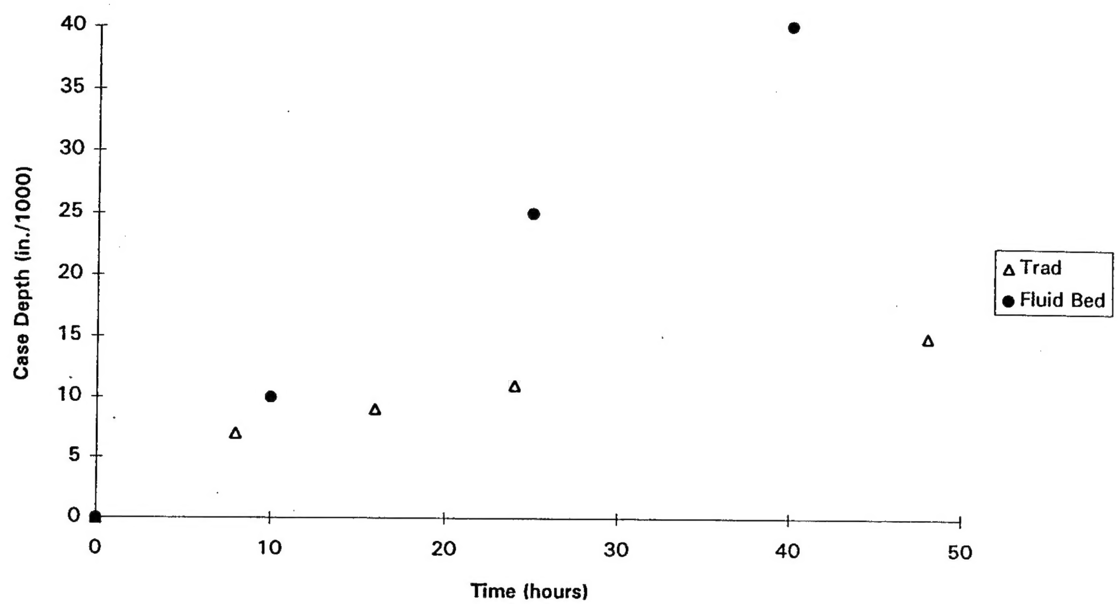
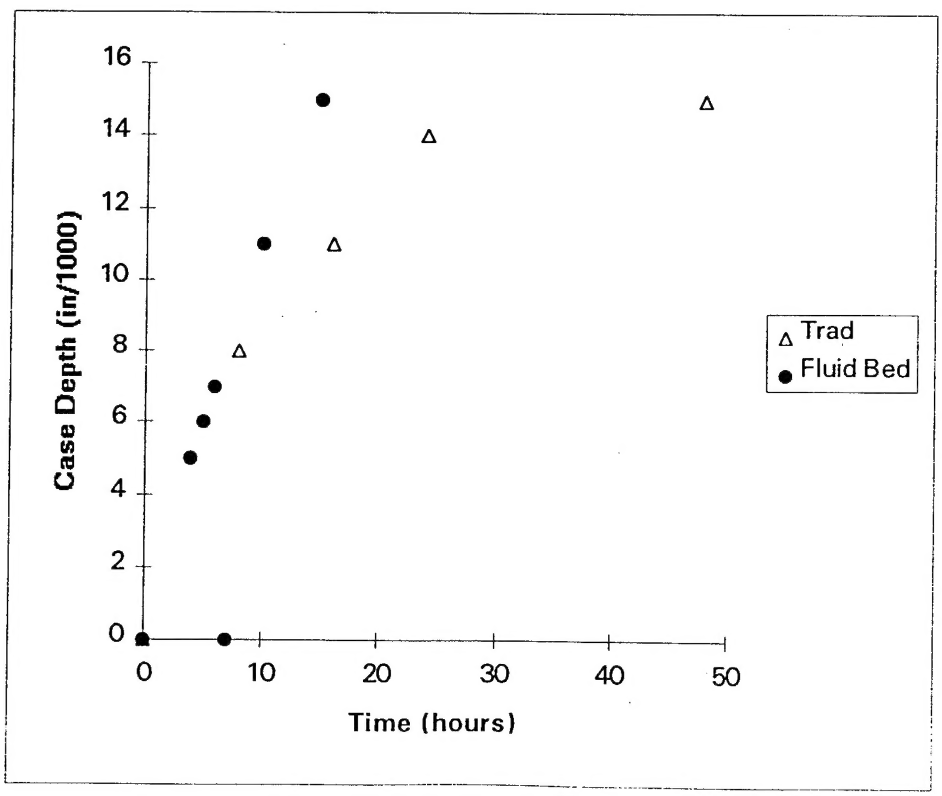


Figure 4: Traditional vs. Fluidized Bed Nitriding on H13



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